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ORIGINAL ARTICLES.

Structural Features of the Alston Block.

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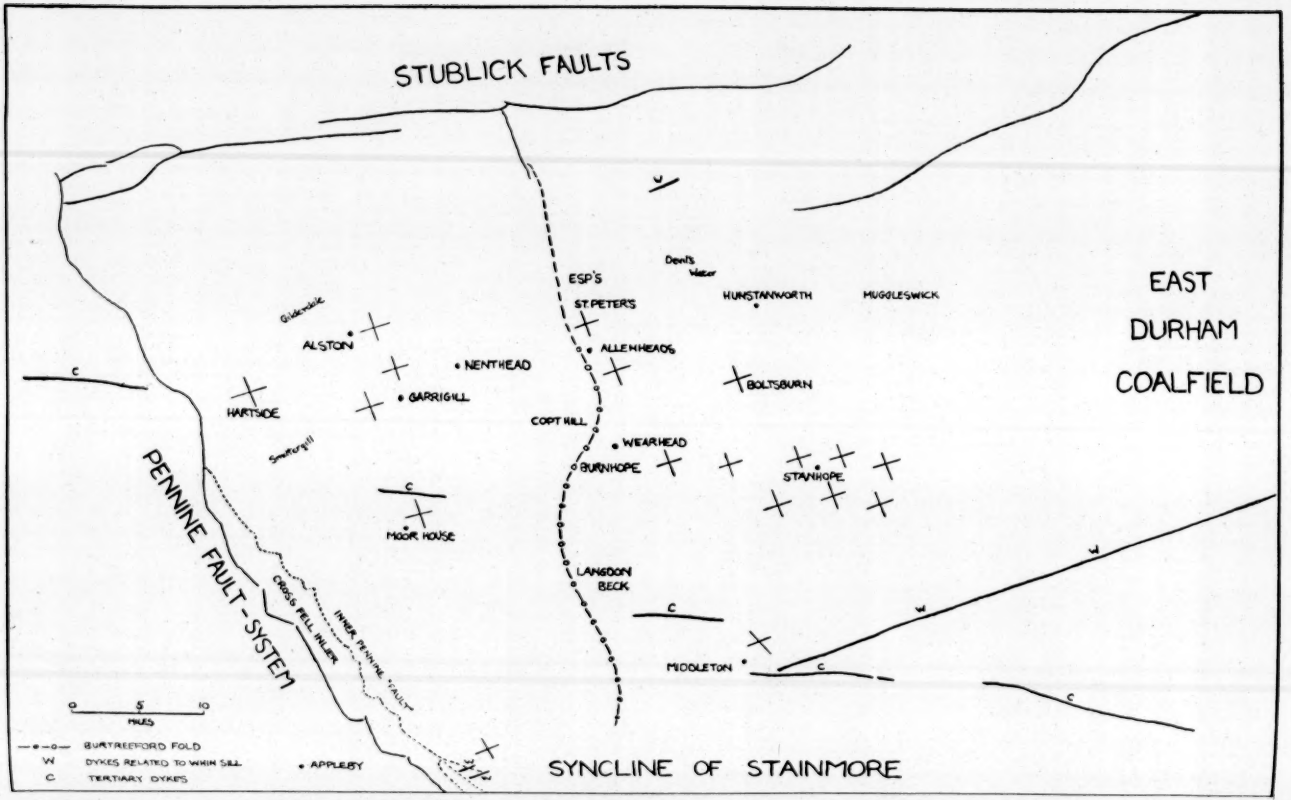
Introduction.

THE Northumbrian Fault-block, forming the central part of the Pennine Chain, is a region of gently tilted Carboniferous sediments, bounded on the north, west, and south by major fault-lines. It is divided naturally into two structurally complementary areas, symmetrically disposed to the north and south of the syncline of Stainmore. The present paper is concerned exclusively with the northern area, named by F. M. Trotter and S. E. Hollingworth the "Alston Block" (1928) [1] and by H. G. A. Hickling the "Cross Fell Block" (1930). The first-named authors, who have recently completed a revision of the Geological Survey sheet covering the north-west corner of the block, have discussed in detail the structure of that district and have described the broad outlines of the tectonic history of the block (1928, 1932).

In the course of an investigation concerned primarily with the mineralization of the Northern Pennines, carried out during the years 1930 to 1932, some attention was devoted to certain structural features of the area. Most of the work was done in that part of the Alston Block lying to the west of the Durham Coalfield. The structural features considered include the joint-system, monoclines and minor thrust-faults, dykes, fissure-veins, and slickensides. The observations are placed on record here since they have a significant bearing not only upon the history of the Alston Block but also upon the more general problems of the relation of dyke- and sill-injection and vein-filling to areal tectonics.

[1] Dates in parentheses refer to list of references at end of article.


STUBLICK FAULTS
Devil's Water
ESP'S
ST. PETER'S
HUNSTANWORTH
MUGGLESWICK
EAST
DURHAM
COALFIELD
Glidersdale
ALSTON
ALLENHEADS
NENTHEAD
BOLTSBURN
HARTSIDE
GARRIGILL
COPT HILL
WEARHEAD
BURNHOPE
STANHOPE
Smallcleugh
MOOR HOUSE
PENNINE FAULT-SYSTEM
LANGDON BECK
CROSS FELL INLIER
INNER PENNINE FAULT
MIDDLETON
0 5 10 MILES
BURTREEFORD FOLD
DYKES RELATED TO WHIN SILL
TERTIARY DYKES
APPLEBY
SYNCLINE OF STAINMORE

The Joint-System.

L. R. Wager (1931) has investigated the joint-system in the neighbourhood of the Craven faults, which form the southern limit of the Northumbrian Fault-block, but no previous study of the joints of the Alston Block has been made. The quarries in the Great Limestone in the Stanhope and Frosterley districts of Weardale lend themselves admirably to such a study. Here, vertical faces are formed by the joints, and quarrying is greatly facilitated by their presence. Approximately a total length of ten miles of limestone face is exposed, and over 1,000 measurements of joint-directions were made, using a rule-compass. The results are embodied in the accompanying diagrams (Figs. 2 and 3). The method of grouping the results adopted in the preparation of these diagrams is that described by F. Smithson (1929). The graphical methods of presentation originated by him are also used. A full description of these methods appears in the paper cited; it will suffice here to state that the readings are corrected to true north, and reduced to read from west to east, 0 to 180 degrees. They are then grouped so that an average figure for the direction-frequency is obtained for every five degrees, thus providing the data from which the graphs are constructed.

Two persistent peaks appear on all the graphs. These correspond with joints running respectively 20–25° west of north (65–70° on Smithson's system) and 60–70° east of north (150–160°). Of these two series the former is somewhat better defined, and the joints are more numerous. Vertical faces in this direction up to 500 yards in length occur in the quarries. Joints in both directions cut through one another, and, as in the case of the joints in the Great Scar Limestone of Craven, described by Wager (op. cit.), there is good reason to suppose that they originated simultaneously, thus constituting a conjugate system of shear-joints. As seen in mine-levels, the joints are closed fractures, which become open only when they reach the zone of chemically active groundwaters. Joints in other directions are very variable; the only other peak in the diagram representing the average directions is at N. 55° W. This peak is mainly produced by the presence of a considerable number of joints in this direction in Rogerley quarry, and suggests a purely local variation.

In addition to the measurements made in the Weardale quarries, a number of observations were made in smaller limestone quarries in the Great Limestone at Greenfield, Hartside Cross, Garrigill (Howhill), Elpha Green, Thornyknowe, Rookhope, and Middleton-in-Teesdale; and in the Scar Limestone at Alston and Westgate. In all these localities, except at Middleton, the same pair of joint-directions predominate; at Middleton the major direction was about N. 45° W., but N. 25° W. was well represented. Limestone-pavements at Long Fell, Westernhope (south of Weardale), in

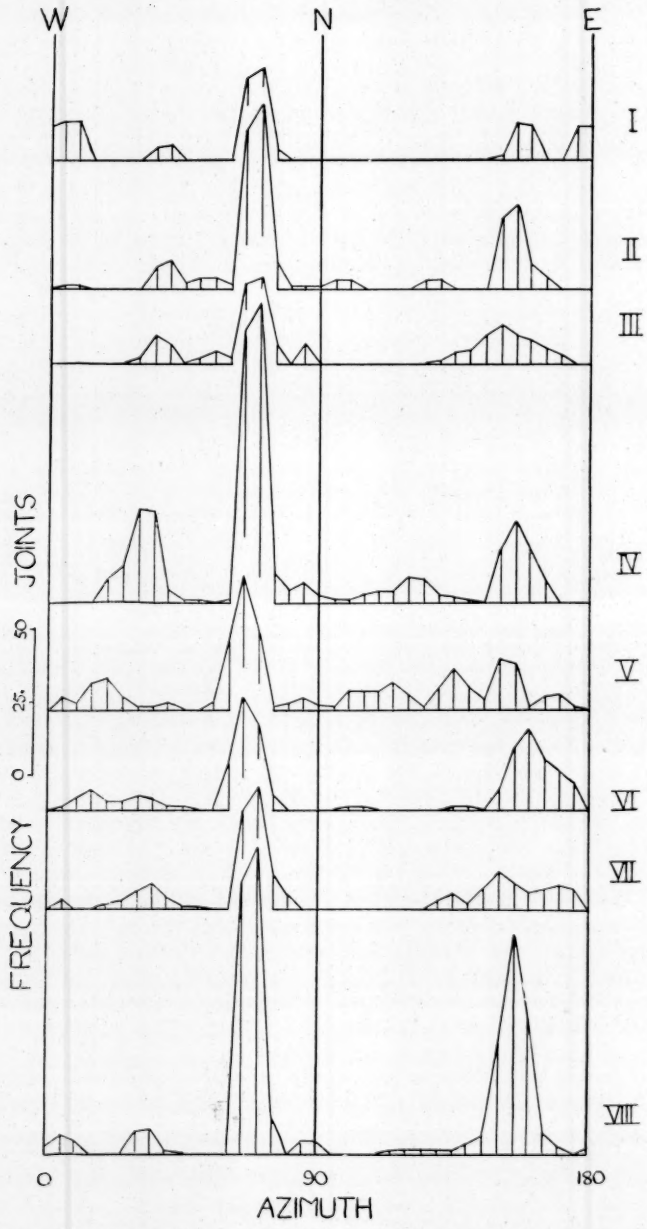


FIG. 2.—Joint-frequency diagrams for quarries in the Great Limestone, Weardale, Co. Durham. I = heights; II = Lanehead; III = ashes; IV = Rogerley; V = Harehope; VI = quarries along Bollihope Burn; VII = Parson Byers; VIII = Newlandside.

Dryburn (Alston Moor), and near Moor House (Upper Teesdale), all showed two joint systems at right angles, the directions corresponding exactly with those in the Weardale quarries. The joints are seldom continuous from one bed to another, but all beds except soft shales are jointed. The joints, however, tend to be somewhat irregular in direction in formations other than limestones and

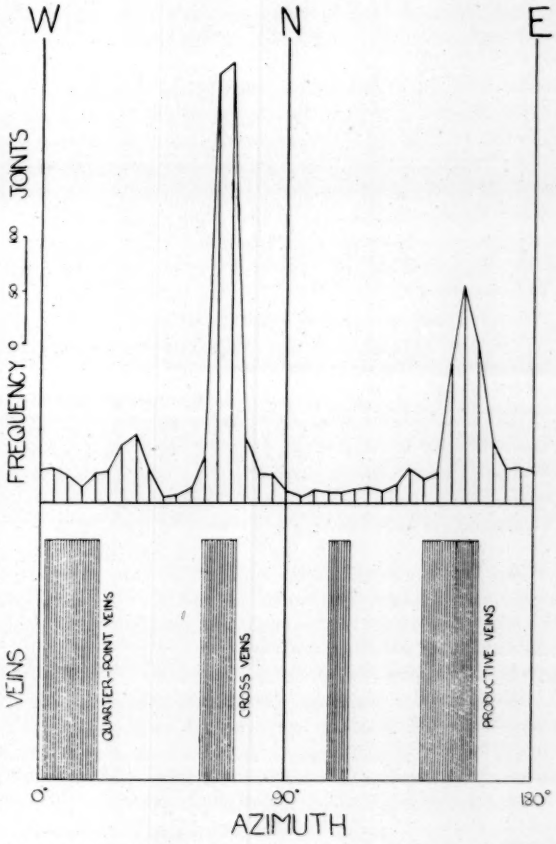


FIG. 3.—Comparison of the directions of mineral veins with the average directions of joints.

massive sandstones. It is noteworthy that in all beds the fractures are vertical to within 3°.

The age of the joints can be fixed by reference to the Whin Sill, the Hercynian age of which has been demonstrated by A. Holmes and H. F. Harwood (1928), for the trend of the quartz-dolerite

dykes associated with the Sill coincides exactly with the north-east joint-direction. Moreover, the Sill shows no jointing comparable with that in the sedimentary rocks, and in spite of its columnar joint-system, formed during cooling, it could hardly have failed to respond to the stresses which produced the conspicuous joints in the sandstones, limestones, and shales into which it was injected, had its intrusion preceded the epoch of joint-formation. The joints are, therefore, regarded as having pre-dated the igneous activity, and as representing the earliest manifestations of Hercynian tectonics.

The widespread and constant nature of the jointing in the North Pennine area makes it reasonable to conclude that the joints were produced by forces acting on a regional scale. Trotter and Hollingworth (1928) have postulated a north-south movement of the block during the earliest phase of the late Carboniferous tectonics, initiating the east-west Bewcastle folding in the thick sediments to the north of the north-west corner of the block. Following the hypothesis proposed by Wager (1931) to account for the joints of the Craven district, it is suggested that the rocks on the rigid block responded to the earth-pressures associated with these movements by jointing, the joints being interpreted as shear fractures symmetrically disposed about the direction of maximum compression. It must be noticed in passing that the direction here proposed does not coincide with that postulated by Wager for the Craven district. There is no evidence at this stage of north-west–south-east regional compression in the northern area.

Monoclinal Folds and Thrust-Faults.

Trotter and Hollingworth consider that the approximately north-south movements, which gave rise to the Bewcastle folding, took place as though the underlying cores of the Alston Block and Lake District–Isle of Man mass moved relatively northward at a greater rate than the Southern Uplands of Scotland. The Lake District, however, being nearer than the block to the Southern Uplands, encountered more resistance, and moved towards the block in a general north-easterly direction. A series of crescentic folds in the north-west corner of the block was thus produced (1928).

Small monoclinal folds and associated thrust faults, trending north-west–south-east, occur in the main part of the block. It is suggested that these were contemporaneous with the crescentic folds mentioned above, and were produced by the same north-easterly compression from the Lake District. Apart from the Burtreeford disturbance, the Whin Sill core of which has been described by W. M. Egglestone (1904) and L. R. Wager (1929), these structures are without mention in geological literature.

The Burtreeford disturbance is the most important of the folds; it is mapped from a point near Allendale Town in the north, to

Hagworm Hill, above Lunedale (Yorks), in the south, thus extending through a distance of twenty-two miles. Proceeding from north to south, the first exposure is at Copt Hill quarry, described by Ecclestone and Wager (op. cit.); further south, an excellent exposure occurs in Burnhope Burn, about one quarter-mile above the new dam-wall now in course of construction by the Durham County Water Board; in Pencilcleugh and several parallel streams at the head of Ireshopeburn, and in a stream one quarter-mile north of the Langdon Beck hotel, the disturbed beds are also visible. No exposures occur in the neighbourhood of Cronkley Scar, south of the Tees, though the apparent displacement of the Whin Sill by the disturbance has profoundly influenced the topography. The fold is visible for the last time on Hagworm Hill, south of which it dies out. In direction, it runs roughly north-north-west, but near Wearhead it pursues a locally sinuous course (Fig. 1).

The monoclinal nature of the fold is apparent from a study of the exposures, in which high dips to the east are the rule. The "displacement" of the fold is a downthrow of some 300 feet to the east in the neighbourhood of Wearhead and Burnhope. Strong evidence of associated thrusting is seen at Burnhope, Pencilcleugh, and near Langdon Beck, for in all these exposures the beds, after dipping steeply to the east, become vertical and then dip to the west. A sudden change of dip to an easterly inclination denotes the development of a thrust-plane. Detailed mapping of the Burnhope exposure showed that the displacement along the thrust plane was of small magnitude. Between Teesdale and the head of Weardale, the disturbance is known to be an overthrust monocline facing east; north of Allenheads, however, it is mapped by the Geological Survey as a normal fault with a downthrow to the west. Unfortunately, no exposures exist in this part of its course, but the abnormal rise of the beds at the western ends of Allenheads, St. Peter's, and Esp's mines suggest that the monocline continues, facing east; and that a later normal fault has followed the line of the disturbance for part of its course.

Running in a north-westerly direction, roughly parallel with the Burtreeford fold, there is a series of less important monoclinal folds, which from their direction are thought to be contemporaneous with it. Following Rowgill beck, south-east of Hartside Cross, is an ill-exposed fold which appears to face east. This fold may be a continuation of the one seen in Smittergill, two miles to the south-west. The monocline in Gilderdale near Alston is much better exposed; again the "downthrow" is to the east. The Welgill cross vein, seen in Nentsbury Haggs level, is a reverse fault, and it is probable that certain other "cross veins" at Nenthead are similar in character; unfortunately, most of them are inaccessible at present. Forster's "Strata" (1883 ed.) contains a diagram of the Smallcleugh Cross vein, which shows the beds dipping to the west near the vein, and further away returning to their normal dip, suggesting

a monocline facing west. Carr's vein is represented as a faulted monocline facing east by Wallace (1863) in a section on the line of the Browngill and Grassfield vein-system. Other north-west folds were observed in the following localities: In Ireshopeburn, near Barbary level mouth; in Knuckton Burn, near the foot of Smithy cleugh; and near Silvertongue old mine, Muggleswick, crossing the Derwent.

Some attention must also be given to the Inner Pennine fault. This was represented by H. A. Nicholson and J. E. Marr (1891) as a continuous fault separating the Older Palaeozoics of the Cross Fell Inlier from the Carboniferous of the Pennines. J. S. Turner (1927) has pointed out that for a considerable distance the Carboniferous rocks rest directly on Skiddaw slates, etc., without a faulted western boundary. He has shown that in Sink beck, east of Knock Pike, the fault is represented by a monocline facing north-east, and that a similar monocline forms the southerly continuation of the Inner Pennine fault from Christy Bank to Brough. Turner further considers the fault to be contemporaneous with the Dent fault. F. W. Shotton, who is engaged on a detailed study of the tectonics of the Cross Fell Inlier, has already hinted that he believes that the Older Palaeozoic rocks of the Inlier were thrust over the Carboniferous rocks in pre-Permian times (1931, discussion on Wager's paper).

Trotter and Hollingworth (1928) consider that the Whin Sill was injected contemporaneously with the crescentic folding in the Brampton district, and Wager (1929) has suggested that the "pitching phacolith" of Whin rock which forms the core of the Burtreeford fold at Copt Hill was intruded during an episode of earth pressure, that is, at the same time as the monoclinal folding was impressed on the area. The significant distribution of a late-stage differentiation-product of the magma is held to support this conclusion. There is, therefore, good reason to suppose that the Sill was injected during the period of action of the north-east compressive stress. It does not cut across the folds in any observed locality, but is in general parallel to the bedding of the sediments, even in the phacolith at Copt Hill. Under the action of the postulated forces, the direction of maximum compressive stress was north-east–south-west, and it is interesting to observe that the dykes related to the Whin Sill, described by Holmes and Harwood (1928) run north-east–south-west, and thus correspond in trend with the direction of maximum compressive stress.

An attractive hypothesis to explain the mechanics of injection of the Sill has been proposed by J. A. Smythe (1930). This involves horizontal movement of beds during injection and is based upon the indisputable fact that the place of a number of limestones appears to be taken by the Sill in Upper Teesdale. Such movement appears to be the only possible mechanical alternative to assimilation, which is shown to be out of the question. No evidence of the

direction of the horizontal movements is as yet forthcoming, but the latter may be tentatively correlated with the horizontal stress from the north-east until confirmation or disproof of this suggestion is provided by further work on the relations of the Sill to the injected formations.

A second series of folds runs in a north-east–south-west direction and appears to be confined to the East Allen, Devil's Water, and Derwent drainages. St. Peter's mine affords an excellent series of underground exposures of one of these. This fold has been mapped during the present work on a scale of 40 feet to the inch, using the Weardale Lead Company's mine-plan. The disturbance is seen at three horizons in the mine in the Great Limestone, and lower down in the Four Fathom and Three Yard Limestones. The axis of the fold pitches towards the north-east, while the monocline faces south-east. This fold is clearly due to top-compression from the north-west. The St. Peter's vein runs parallel to the fold, approximately along the north-east axis, at the Great Limestone horizon, and has not yet been reached at lower levels. Since it is filled with mineral material, it is considered to be a tension fissure ; the undisturbed nature of the vein-stuff suggests that the compression causing the folding preceded the tension fissuring.

A disturbance exactly on the line of St. Peter's fold was discovered in the Devil's Water, east of Harwood Shield, in Steel Crags Wood. The western exposure of this fold, at the point where the Devil's water changes its course from north-east to east, corresponds exactly with the fold as seen in St. Peter's mine ; further east, near the end of Steel Crags Wood, the fold appears to be anticlinal in nature. Here the vein can be seen, again on the north-west side of the fold. Parallel to the St. Peter's fold, and presumably due to the same compression, is an asymmetric anticline beautifully exposed at Coal Crag in Knuckton Burn, where it determines the course of the stream eastward for some distance. Another exposure occurs near the waterfall in the same stream at Linn Bank wood. A series of monoclinal folds also occurs in Whiteheaps mine, Hunstanworth. The axes of these appear to run north-east–south-west ; two monoclines face north-west, and one south-east. These folds are traversed by a series of veins running east and west within a few degrees, the White, Red, Red String and Company's veins. The White vein and sometimes the Red vein attain widths of upwards of 30 feet and certainly cannot be regarded as the results of compression ; here again, the undisturbed mineral material is an argument for the earlier date of the folding.

The relative ages of the north-west and more local north-east folding cannot be fixed by direct observation ; but the north-east folds may be explained most readily as later features. The continued operation of the compression from the Lake District ultimately brought about a clockwise rotation of the block, according to B. Smith (quoted by Trotter and Hollingworth, 1928, p. 446), with

tearing along the Stublick fault-line, which forms the northern boundary of the block. Such movements might well imply a more rapid eastward movement in the northern part of the block than in the region to the south. Experiments carried out by W. J. Mead (1920) show that under these conditions north-east folds would be produced (Fig. 4).

It is now possible to sum up the first phase of Hercynian tectonics in the Alston Block. Three distinct stages have been recognized:

(*a*) General north-north-east earth pressures giving rise to a conjugate regional joint-system on the block, with fractures running N. 20–25° W., and N. 60–70° E.

(*b*) Compressive stress from the Lake District, directed north-east, producing a series of north-west–south-east monoclines and

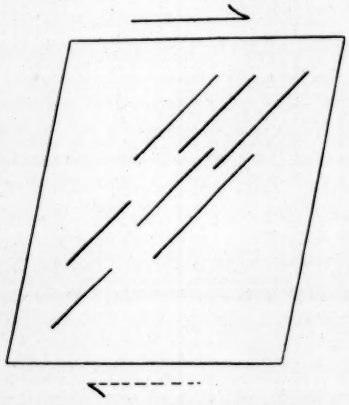


Fig. 4.—Production of north-east trending folds by shearing stress occasioned by the "clockwise rotation" of the Block, according to the mechanism demonstrated by W. J. Mead.

minor thrust faults, including the Burtreeford disturbance and possibly the Inner Pennine Fault. Horizontal movements probably occurred and the Whin Sill and related dykes were injected at this stage.

(*c*) Shearing stress occasioned by the clockwise rotation of the block under the influence of the continued compression from the Lake District, giving rise to local strong north-easterly folds.

Doming and Mineralization.

Mineral veins occur in considerable numbers over the western part of the block, in which the Lower Carboniferous sediments outcrop. A structure-contour map constructed for this part of the area showed that it is a "nose" closing to the east; but as the Pennines have received an easterly tilt in times much more recent than Hercynian, as shown by H. G. A. Hickling (1930), it seems probable that the original structure was a dome, with its

long axis running roughly east-north-east. Hickling has called attention to the very gentle nature of this folding. There is, moreover, evidence that the fissuring, fissure-filling and doming all took place at the same time, for it is a proven fact in the mining field that the productive fissure-veins, in the area covered by the dome, become progressively narrower as they are followed downwards, until finally from an economic, though not from a geological point of view, they die out. A full discussion of this question will follow in a future paper ; it must suffice here to state that such conditions can be accounted for most satisfactorily by assuming the contemporaneity of doming and mineralization.

The general character of the mineral veins have been summarized in a previous publication (Dunham, 1931), in which a map of the veins is to be found. The veins occur in four directions which persist throughout the field, an area of some 800 square miles. These directions are inserted on the joint diagram (Fig. 3) ; it will be observed that while two sets of veins coincide with the master joint system, two entirely new directions were initiated at this period. These, the " Quarter-Point " veins (roughly east-west) and the unimportant suite at right-angles are unrepresented in the joint system except at Heights quarry, which is adjacent to the Slitt vein, a long vein running N. 82° W. at that point. It is a phenomenon of general occurrence that fracturing of an area which has suffered previous jointing or fissuring either follows the direction of the previous fractures, or takes place at about 45° to them. The present area is no exception to the rule. An additional illustration of the control of direction by the master joint system is afforded by the swinging-round of certain east-west veins to the north-east direction. The Browngill and Bentyfield veins of Alston Moor, the Capleclough and Longcleugh veins south of Nenthead, and the Trough vein above Grasshill are striking examples.

The veins should not be confused with widened joints, for they are invariably associated with faulting of small magnitude, and further, do not pass vertically through the shale beds as do the joints, but assume a steep hade. A diagrammatic section of Wolcleugh Old mine in the Geological Survey Special Reports on Mineral Resources given by Carruthers (1923) shows this tendency clearly ; it is found to be a characteristic feature of the veins throughout the mining field.

Mineralogical evidence which will be presented in a forthcoming paper shows that veins in all directions, with the exception of the Great Sulphur vein-system of Alston Moor, were filled simultaneously. L. Thompson (1915) has shown that the latter, an east-west vein-system some eight miles long, with accompanying north–north-east veins, is later than the normal lead veins. This represents a purely local manifestation of the mineralization, and was the last of the Hercynian episodes of activity in the Alston Block.

The fissure veins are thus considered to have been produced by

torsional stresses set up during the doming of the western part of the block. The irregular walls of the veins, which appear as though they had been torn apart, are consistent with the interpretation of the veins as tension gashes.

Post-Hercynian Tectonics.

Of the history of the Pennines during the Mesozoic era, very little is known, except that from the point of view of orogenesis and igneous activity, it was a period of quiescence. In Tertiary times, however, two events of great importance took place:

(*a*) The tholeiite dyke-swarm, focussing upon Mull, was intruded in a series of linear échelons (Holmes and Harwood, 1929). The direction of these coincides exactly with that of the "Quarter-point" veins. In Teesdale, a tholeiite dyke actually occupies a fissure the eastward prolongation of which is continuous with the Lodge Sike vein. The Tertiary dykes cut the mineral veins; they were, however, intruded before the initiation of the present topography.

(*b*) The uplift of the Alston Block along the line of the Outer Pennine fault took place; movement along the Stublick faults also occurred. Both of these faults cut Triassic strata. This uplift, which was contemporaneous with the uplift of the "Rigid" (Ingleborough) block south of Stainmore, gave the predominant easterly tilt which has controlled the topographic features of the area.

These earth movements were accompanied, in the lead veins and along certain of the joints, by the formation of horizontally striated vertical slickenside-walls. Beautifully striated slickensides occur in all veins almost without exception, and cut all minerals impartially. Locally, the slickensides may be associated with brecciation, or may be replaced by breccias. Examples of such tectonic breccias were observed in Boltsburn mine in the vein at the 34-fathom level east, at Billinghills mine, and at Westernhope old mine. A thin section of the Boltsburn example revealed a typical angular breccia, composed of fragments of fluorspar and galena. The facts that the slickensides polish limonite derived from siderite by oxidation, and that the breccia from Westernhope contains galena fragments surrounded by cerussite, are significant, for they show that the movement has taken place since the veins approached within a few hundred feet of the land surface. It is not impossible, of course, that crustal adjustments have taken place along these lines in post-Tertiary times.

Conclusion.

The structural features of the Alston Block, since it is not a strongly folded region, are comparatively simple. The author nevertheless realizes that the mechanical explanations here advanced to account for those features probably err on the side of simplicity, owing to

present limitations of knowledge concerning the details of earth-mechanics. More confidence is to be placed in the general sequence of events proposed. Table I summarizes the salient features of the Hercynian and Tertiary tectonics.

ACKNOWLEDGMENTS.

The author wishes to acknowledge with gratitude helpful criticism and advice from Professor Arthur Holmes, under whom the investigation was carried out. He also wishes to thank Dr. W. Hopkins for discussing with him some of the problems of the area; Mr. J. Alvin Hill for assistance in the mines, and Mr. George Wherry for help in the field. He is grateful also to many friends in the Universities of Durham and Harvard for discussion of the results.

TABLE I. SUMMARY OF MINOR STRUCTURAL FEATURES OF THE ALSTON BLOCK.

		West. 0–10°	65–70° North.	90–100°	150–160° East.	Horizontal.	Regional Stress and Movements.
TERTIARY.		Slickensides. Tholeiite Dykes					Uplift of Block along Pennine and Stublick Faults.
HERCYNIAN PHASE II.		Great Sulphur Vein. "Quarter-Point" Veins.	"Cross" Veins.	Small Veins. Small Veins.	Productive Veins.		Torsional Stresses; Doming.
HERCYNIAN PHASE I.	Stage 3.				Monoclinal and Assymetric Folds		Rotation of Block; Local Shearing Stress.
	Stage 2.		Monoclines and Thrust-faults.		Quartz-dolerite dykes.	Whin Sill: Horizontal movements of beds.	North-east compressive stress.
	Stage 1.		Master-Joints.		Master-Joints.		General north-south compressive stress.

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The Tectonic Development of the Western Weald in Lower Cretaceous Times.

By J. F. Kirkaldy, M.Sc., F.G.S., King's College, London.

1. Introduction.
2. The Palaeogeography of Aptian Times.
3. The Growth of the Western Weald.
4. The Effects of Pressure on the Wealden Geosyncline.

1. Introduction.

MODERN detailed stratigraphical studies have demonstrated very clearly the long and involved tectonic history of the majority of the main structural units of England. It has been proved that, in certain areas, the thickness and the lithology of the sediments were partly determined by repeated pene-contemporaneous folding along definite axes, and thus it has been possible to trace the gradual growth of some of the main fold lines of the country. The Weald is typical of these areas, whose structure, at first sight simple enough, reveals on closer study much complexity of the

minor folding and faulting and also gives evidence of long continued movement along certain lines ; movement contemporaneous with the deposition of beds which were involved in the final crescendo of tectonic activity.

Thanks to Lamplugh's pioneer work on the deep borings in Kent (1)[1] we now know that the superficial corrugated dome of the Weald overlies an important geosyncline which was the site of almost unbroken sedimentation throughout Mesozoic times. It was not until the end of Cretaceous times that depression finally gave place to elevation and that the present anticlinal structure first took shape. Exactly how much of the " Wealden island " remained land during the deposition of the Eocene Beds of the neighbouring London Basin is still uncertain, but it is probable that the area was never completely submerged. The present structural elements visible in the Weald are the result of the furthest-felt ripples of the Alpine earth storm. It should be strongly emphasized that the structure of the Weald is not nearly so simple as is commonly supposed to be the case. In essence it is an anticlinorium with a complex and as yet imperfectly understood system of minor strike faults and folds crossed by dip faults and in its western end by N.–S. monoclinal lines. Since the formation of these folds in middle Tertiary times there has been no further folding, but a uniform elevation of the area as is shown by the unwarped character of the early Pliocene plain of marine denudation at about 550 feet O.D. and also of the late Pliocene or early Pleistocene 200 ft. platform.

The present paper summarizes the chief results of a detailed stratigraphical study of a large part of the Lower Greensand in the area west of Pulborough and Dorking. A detailed account of the field work is being published elsewhere ; but it will be shown here that some of the main structural lines now visible in the Western Weald were already beginning to appear in Lower Cretaceous times.

2. The Palaeogeography of Aptian Times.

At the beginning of Cretaceous times, western Europe formed a land mass separating the Tethys from a Boreal ocean which covered parts of Eastern England and Germany. The higher parts of the surface of this land mass were formed, as to-day, by the isolated Armorican massifs, and it was through the passage of the Côte d'Or between the Massif Central and the Vosges that an arm of the Tethys extended northwards into the Paris Basin. The English Wealden Beds represent the deposits of rivers draining southwards and south-eastwards into this sea, whilst the presence of very similar beds in Hanover indicates the existence of rivers flowing northwards from the slate massifs into the Boreal ocean.

Examination of the littoral deposits of the sea over Northern France shows that considerable changes in the position of the shore

[1] Figures in parentheses refer to References at end of article.

lines took place during Neocomian times, but it was not until the beginning of Aptian times that a transgression of greater magnitude than those of earlier date flooded the delta plain and carried marine conditions right across South-Eastern England. Even then the Palaeozoic area of the London Platform remained unsubmerged and a shallow epicontinental sea extended round its western end to join at times with the Boreal ocean.

The basal beds of the Lower Greensand, the Atherfield Clay and the Hythe Beds (Fig. 1) were probably restricted in their original extent to the old Wealden geosyncline and its extension south-westwards into the Isle of Wight, and it was not until the deposition of the Sandgate Beds, which are equivalent to the Bargate and the Puttenham Beds of Fig. 1, that a marine transgression carried the sea beyond these limits and opened a passage round the western end of the London Platform to connect the Boreal ocean with the sea over Southern England. In the paper already mentioned evidence has been brought forward for regarding the scattered outcrops of the Lower Greensand along the foot of the Wiltshire and Berkshire Downs as equivalent to the Sandgate Beds of the Weald, whilst in the Boulonnais (2) and in the deep borings under Kent (3) we also have evidence of the transgressive nature of the Sandgate Beds.[1] This extension of marine conditions was probably relatively short-lived, for though we have to make allowances for an unknown amount of pre-Gault erosion, it is not until we reach Stone, near Aylesbury, that we find any beds which can be easily correlated on lithological characters with the Folkestone Beds. These beds and the thicker development of similar sands around Leighton Buzzard are probably deposits to be associated with the Boreal Sea. The exact mode of origin of the Folkestone Beds of the Weald is still uncertain, but my friend Mr. Shepherd's discovery of marine fossils in the Folkestone Sands of the Farnham area [2] suggests that they are, in part at least, the deposits of a shallow sea of rather limited extent into which were blown large quantities of sand from the surrounding land surfaces ; whilst, in part, they are probably of continental origin, as were the lithologically similar Bagshot Sands of the western part of the London Basin.

3. The Growth of the Western Weald.

The abrupt change in conditions, due to the advance of the sea over the surface of the Wealden delta-plain, is indicated both by the incoming of a marine fauna and also by the " ravinement "

[1] The " hand specimen of topmost Atherfield clay at Dover, with bored crypts of Pholadidea descending from the base of the Sandgate Beds ", which is figured as the frontispiece of the 1911 Memoir " On the Mesozoic Rocks in some Coal Explorations in Kent ", gives striking evidence of this transgression.

[2] The importance of this discovery lies in the fact that fossils had previously only been recorded from the Folkestone Sands of East Kent, where the beds are of a different lithological character than the clean sands of Sussex and Surrey.

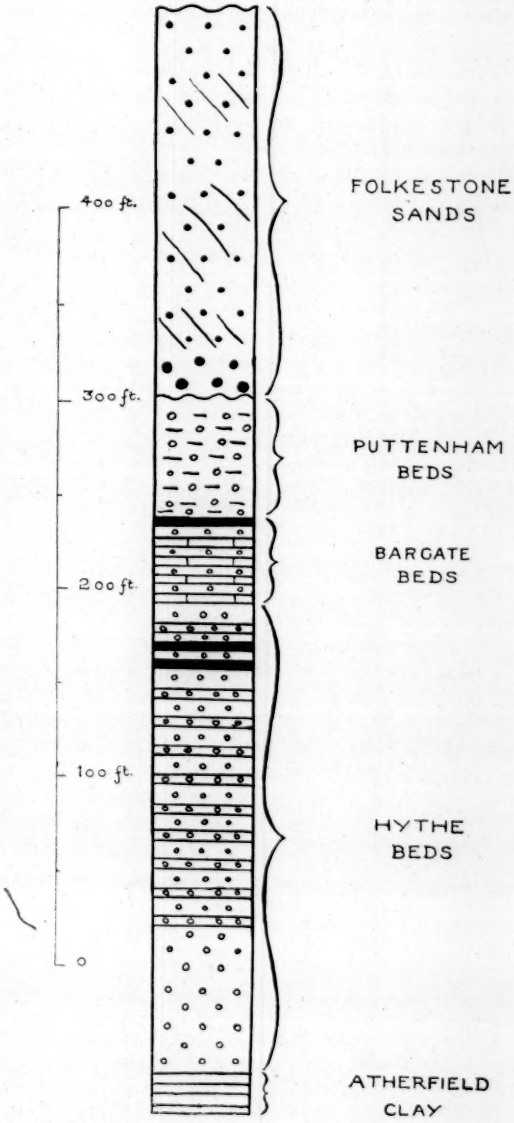


FIG. 1.—Generalized Succession of the Lower Greensand of the Western Weald.

of the top beds of the Weald Shales. This change is further emphasized in the Isle of Wight by the Perna Bed, a bone bed which can be compared, from its position at the base of a marine succession, with the Rhaetic Bone Bed. Above this break occurs the so-called "Atherfield Clay", which varies considerably both in lithology and in ammonite fauna. Locally, in the Weald, the bed appears to be entirely absent, and it is probable that the first beds to be deposited by the transgressing Aptian sea consisted in some areas of the reddish silts of the Atherfield Clay and elsewhere of the fine sands which are usually regarded as the basal

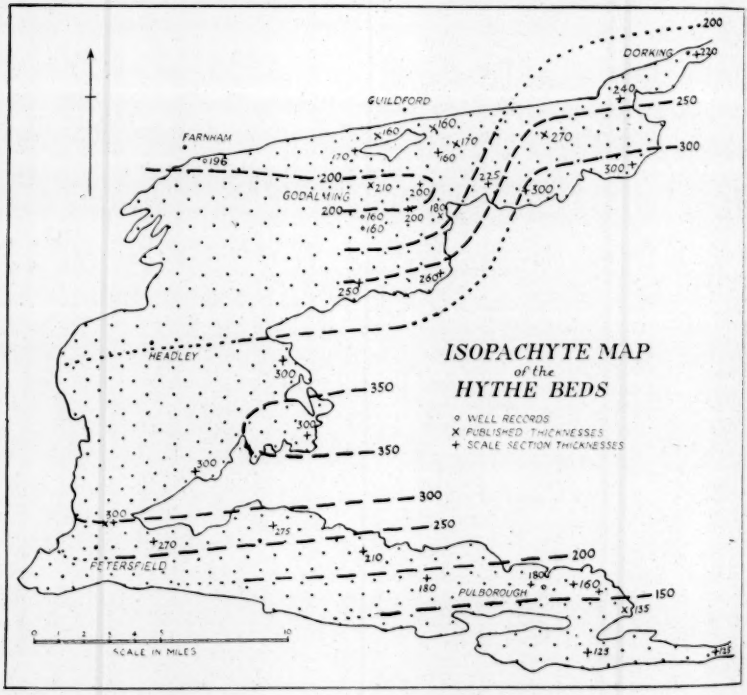


FIG. 2.

member of the Hythe Beds. Then followed, in the Western Weald, a period of steady sinking of the axial region of the geosyncline. (Fig. 2, which illustrates this point, was constructed partly from published well records and estimates of thickness and where these data failed use was made of carefully drawn dip sections. The nature of the data used in each case is noted on the diagram.) At first only fine-grained sands were deposited, but, as the infilling of the geosyncline progressed, the deposits became coarser in character and glauconite began to make its appearance in some abundance.

This period of relatively clear water conditions was evidently favourable to the growth of sponges, the silica of whose spicules helped to cement together bands of sandstone and locally to form cherts. These are the beds which are generally said to be of the "cherty facies" of the Hythe Beds, but it must be pointed out that true massive cherts are only locally developed, as in the Leith Hill and Petworth areas, and that the bulk of this formation consists of soft sands and sandstones with very subordinate cherty bands. The abundance of fragments of chert in the high level gravels of the North Downs and of the London Basin suggests that the sponges may have originally flourished in the central parts of the geosyncline and that we have preserved to-day only scattered portions of the fringe of the sponge belt.

The only interruption to continuous depression during this period appears to have occurred along the line of the Pease Marsh anticline in the Godalming neighbourhood. As will be seen from Fig. 2, the usual steady thinning of the Hythe Beds towards the margins of the geosyncline is interrupted to the south of Godalming by a narrow E.–W. zone along which they are only about 160 feet thick, whilst in the complementary depression along the line of the Wey Valley they have increased in thickness to nearly 250 feet. Deep wells are more closely spaced here than in any other part of the area so that there can be no doubt as to the reality of these rapid variations in thickness. The officers of H.M. Geological Survey who first drew attention to these phenomena (4) regarded them as evidence of minor folding of pre-Bargate Bed and post-Hythe Bed date and claimed that the Bargate Beds were unconformable on the Hythe Beds. They urged in support of this view the presence of the pebble bed with scattered phosphatic pebbles, which Meÿer had described from the base of the Bargate Beds around Godalming (5). Such differences of thickness, however, are capable of more than one explanation (Fig. 3). Let us consider for a moment a somewhat comparable case in the London Basin. If we examine the thickness of the Thanet Sands passed through by a chain of wells running in a N.–S. direction across the Basin, we find that near Dunmow the beds are 30 feet thick, that they thicken southwards to a maximum of over 100 feet at Rayleigh, then decrease in thickness to about 80 feet at Gravesend, increase southwards again to 100 feet near Rochester, whence they decrease steadily in thickness against the southern side of the Basin (6). Moreover, throughout a large part of the London Basin there is a distinct pebble bed at the base of the Woolwich Beds. We might deduce from this evidence that the Thanet Sands were slightly folded in pre-Woolwich Beds times and that there is an unconformity at the base of the Woolwich Beds. This, however, is known not to be the case. All that we are seeing here is the effect of movement along a contemporaneous axis of warping, the Thames Valley anticline, which has controlled the thickness of the Thanet Sands.

Similar effects resulting from posthumous movements along fold-lines have been proved many times in Britain. The abnormal intensity of the middle Tertiary movements along the Hog's Back shows that this area is evidently one of considerable structural weakness and it is, therefore, probable that slight movement in this belt may have controlled the sedimentation of the Lower Greensand.

It should be possible to devise criteria for distinguishing between the two rival explanations. If, as suggested above, these variations in thickness are original, we should expect to find the Bargate Beds everywhere in contact with the same horizon at the top of the Hythe succession. If on the other hand, as suggested by the officers of H.M. Geological Survey, as much as 90 feet out of a total thickness of 250 feet of the Hythe Beds have been removed in places we should

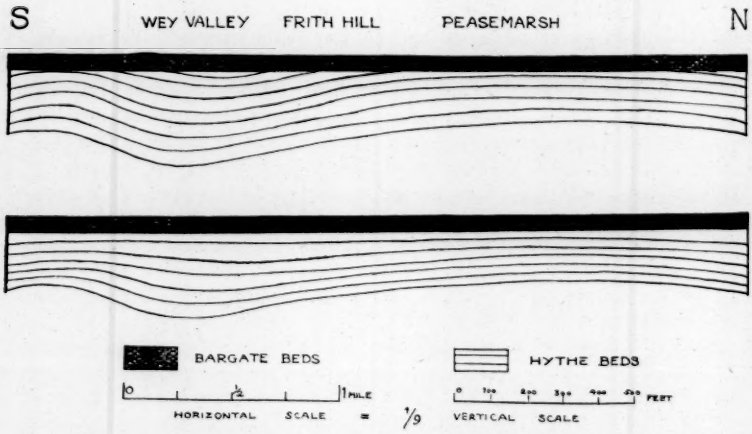


FIG. 3.—Two interpretations of the variation in thickness of the Hythe Beds at Godalming.

expect to find the Bargate Beds resting on different horizons of the Hythe Beds. The Hythe Beds of this neighbourhood are admittedly somewhat difficult to split into lithological units, but it is found that the greatest development of stone bands occurs at and above the middle of the succession and that above this horizon sands tend to predominate. Examination of the various critical sections along the axis of uplift to the south of Godalming shows the Bargate Beds in all cases resting on very similar sands, with the stone beds developed some distance below, as would be expected to be the case if the differences in thickness were due to steady continuous movement.

So far nothing has been said as to the evidence of the pebble bed at the base of the Bargate Beds. It has been carefully examined at

all possible exposures and whilst it certainly contains a considerable proportion of brown phosphatic nodules and often overlies the top members of the Hythe Beds with a sharp lithological line, in no case has evidence of definite unconformity been seen. Moreover, its geographical extent is small, for it is completely absent in the sections to the east of Abinger and when traced southwards from Godalming it decreases both in thickness and in the size of the constituent pebbles and cannot be recognized to the south of Eashing. Again, in Sussex there is every sign of a passage between the Bargate Beds and the Hythe Beds. Yet if the movement at Godalming was big enough to justify the term " unconformity " we might expect some evidence of at least a pause in deposition only 14 miles to the south.

It, therefore, seems reasonable to regard the sedimentation of the Hythe Beds of the Godalming area as having been controlled by slight minor folding. The presence of small pebbles of quartz and lydite in the uppermost members of the Hythe Beds in the adjacent areas (7 and 8) gives evidence of the final silting up of the geosyncline and we can regard the pebble bed at Godalming as due to an accentuation of this process. Near the margins of the geosyncline at this final stage a phase of local inhibited deposition without actual erosion would be developed owing to the sea-bottom having reached the level of " wave-base " (9) and thus the resultant removal of the sand would lead to a concentration of pebbles. The unstable nature of the sea-bottom in the Godalming area may possibly have carried this phase farther southwards than in the areas to the east, where it is hidden beneath the overlying Upper Cretaceous beds.

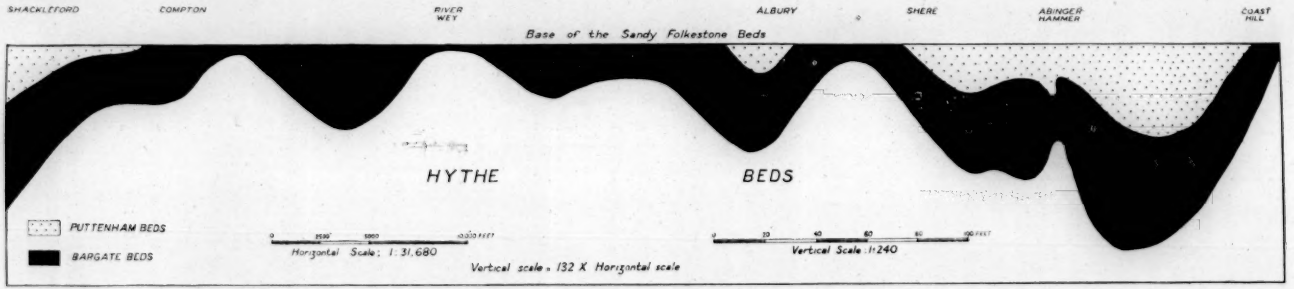
After this digression into the exact date of the movements around Godalming we can proceed with the later history of the area. A geographical change on the London Platform brought a flood of Jurassic material pouring into the area. This produced a littoral belt of coarse shelly sands passing southwards into finer grained calcareous sands and possibly muds, which to-day form the Bargate Beds (see Fig. 1). These beds have been traced as a continuous phase of calcareous deposits from Dorking, where they are interbedded with the silts of the Sandgate Beds, past Godalming, Headley, and Petersfield to Pulborough. This change cannot have been of any great magnitude, for the detritus soon became finer in grade and finally a second chert phase marks a brief return to the conditions of the Hythe Bed times.[1] The area in which sponges flourished during this second phase was evidently less extensive than during the preceding one, for this Upper Chert is restricted to the northern parts of the trough and has not yet been identified in Sussex. Then

[1] It must be emphasized that the change from the arenaceous Hythe Beds to calcareous Bargate Beds does not imply actual unconformity, but may be taken as indicating a slight change in the geography of the surrounding land areas.

followed a period of quieter sedimentation comparable with that during which the Hythe Beds were deposited ; but, on the whole, a larger amount of clayey material was brought into the area. This influx appears to have rapidly killed off the sponges, and as a result a considerable thickness of rather monotonous clayey sands, the Puttenham Beds, was laid down.

A study of the field relations of the Bargate and the Puttenham Beds in the area between Westcott and Compton reveals several curious features. Whilst the Puttenham Beds cover large areas to the west of Compton, they are entirely absent along the line of the Wey Valley, though just appearing at Albury, only to disappear again for a short distance before showing quite an extensive outcrop in the neighbourhood of Abinger Hammer. Although the Bargate Beds appear to be present as a continuous sheet throughout the whole of this area, they also show significant changes in thickness and lithology. The possibility that these phenomena might be due to gentle warping of pre-Folkestone Sand date was suggested by the diagram in the Guildford Memoir (4, fig. 3, pl. 14), showing the variations in the thickness of the various units of the Lower Greensand. This hypothesis was tested by making careful measurements of the full thickness of the Bargate and Puttenham Beds which are so well exposed in the numerous sunken lanes of the area in question. These measurements were then plotted along an E.–W. (strike) line of section and the country between the various lanes examined for evidence of any change in the thickness of the beds. The data thus obtained are embodied in Fig. 4 which shows that the Sandgate Beds display systematic variations of thickness, which may be plausibly attributed to gentle warping along axes spaced at about 2-mile intervals.

It is stated in the Guildford Memoir " that continuous movement prevailed throughout the district in Lower Cretaceous times is indicated by the different thicknesses of the members of the Lower Cretaceous series " (4, p. 10), but few details of its operations are given. Detailed study of the lithology of the beds suggests that these axes were in movement whilst the Bargate Beds and the Puttenham Beds were being deposited, and the latter beds, in particular, were probably unequally deposited over the area. There must also have been some slight erosion of the Sandgate Beds before the deposition of the Folkestone Sands. This last statement is not meant to imply subaerial erosion, but merely a lifting of the sea bottom into the zone of wave action, i.e. above " wave base ", and as a result of this warping, combined probably with unequal deposition, the Puttenham Beds are to-day preserved only in the slight downfolds, e.g. the small outlier to the south of Albury (see Fig. 4). Strong confirmation of this suggestion is afforded by the fact that a break of sedimentation at the base of the Folkestone Sands is evidenced throughout the Weald. Near Ashford the basal pebbly sands of the Folkestone Beds rest with a clear-cut junction on the silts of



THE PRE-FOLKESTONE FOLDING OF THE BARGATE AND SANDGATE BEDS

FIG. 4.

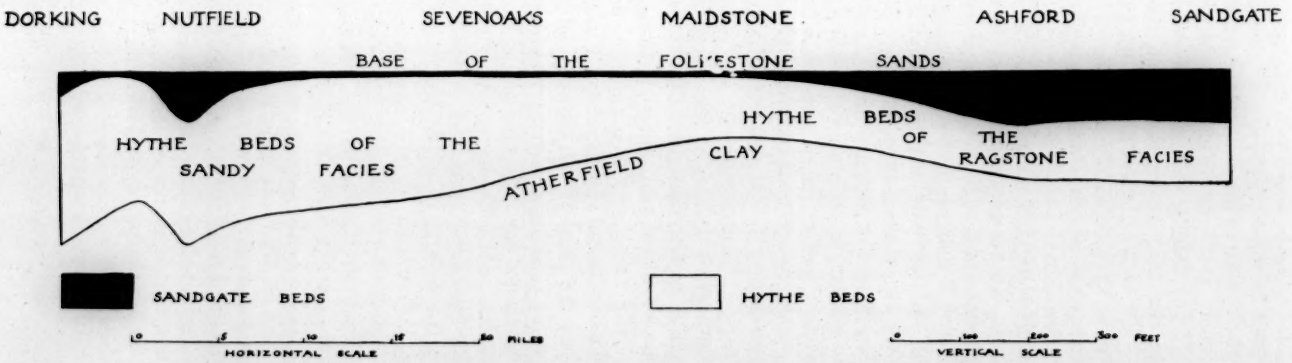


FIG. 5.—The variations in the thickness of the Sandgate and the Hythe Beds between Dorking and Sandgate.

the Sandgate Beds, whilst a few miles north-westwards at Sandway, near Lenham, several pits show exceptionally coarse pebble beds at the base of the Folkestone Sands.[1] A comparable pebbly development has been traced by Gosling from Nutfield to Brockham (7, pp. 233–4), and is to be seen between Dorking and Guildford in the area under discussion (see also Fig. 5).

The trend of these axes of warping was found by the field evidence to be approximately north-south (i.e. nearly at right-angles to the fold axes of the Hythe Beds–Bargate Beds date). Fig. 5, which represents the variation in thickness of the Hythe and the Sandgate Beds along the northern side of the Weald, clearly suggests that this pene-contemporaneous folding was a widely developed phenomenon. The details have yet to be worked out in many areas, but it is interesting to note that Gosling has suggested the presence of strictly comparable phenomena to account for the peculiar lithological characters and the limited lateral extent of the Fuller's Earth of the Reigate area (7, p. 256), whilst J. W. Evans refers to similar, though more intense, pene-contemporaneous folding of slightly earlier date in the Boulonnais (10).

The present topography of the Western Weald clearly shows the presence of N.–S. structural lines crossing the more normal E.–W. folds. Examination of a geological map shows the markedly rectangular nature of the outcrop of the Lower Greensand, which is due to the presence of N.–S. monoclines with a westerly downthrow. These monoclines, if named from the chief physical features of the area, are, reading from east to west, the Leith Hill, the Hascombe and the Hindhead-Elstead flexures. It is rather suggestive that the chief E.–W. lithological variations in the character of the Lower Greensand appear to be associated with these lines. These variations are the change in facies of the Hythe Beds and the appearance of the Bargate Beds near the Leith Hill line (8, p. 15); the transition from the "arenaceous" facies of the Hythe Beds on the west to a calcareous "rag and hassock" facies on the east of Pulborough on the extension of the Hascombe line; and the passing of the ironsands of the Puttenham Beds into loams at Selham in Sussex on the continuation of the Hindhead–Elstead fold (see Fig. 6). This is strictly comparable to the facies changes along N.–S. monoclines in the Eocene Beds of the London Basin which S. W. Wooldridge has described (6 and 11). These monoclines must obviously be related to the general N.–S. warping of the sea bottom during the deposition of the Sandgate Beds and the present physiography of the area clearly shows that the major lines must have moved again at some subsequent date during Tertiary times.

It is, therefore, believed by the writer that the sedimentation

[1] An important section at Stone Street to the S.E. of Seal shows coarse basal Folkestone Sands containing boulders and pebbles of a pinkish Fuller's Earth, which were evidently derived from the Sandgate Beds.

of the lower beds of the Lower Greensand was controlled by a combination of E.–W. folding and warping of the sea bottom along N.–S. lines. In the north-western part of our area it has been shown that there were closely spaced axes of warping which reached their maximum effect along the line of the Hascombe monocline. Farther

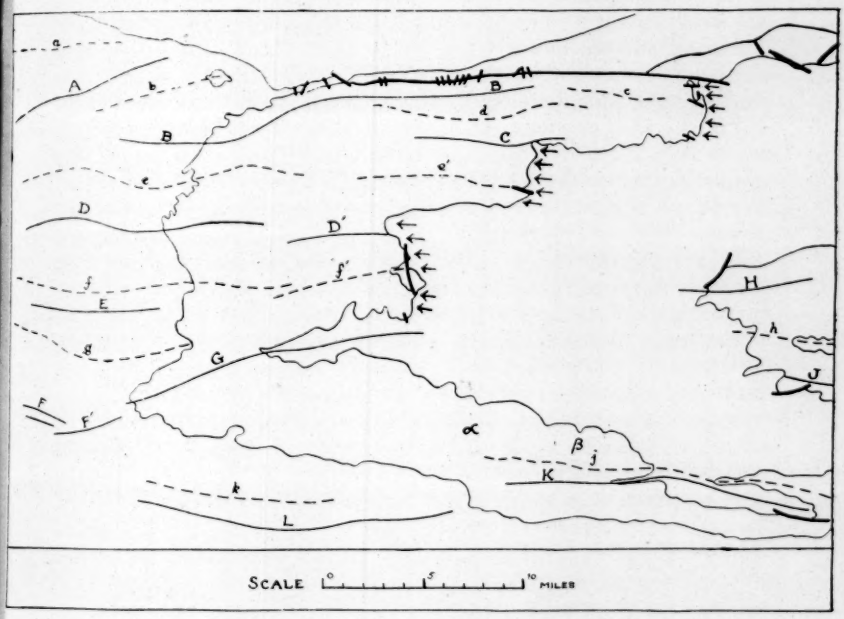


FIG. 6.—Structural Map of the Western Weald. The faults are indicated by thick lines, the axes of the anticlines by thin lines, and the axes of the synclines by broken lines. The lines of arrows mark the approximate position and direction of downthrow of the transverse monoclines. The geological boundaries shown are the base of the Tertiaries, the base of the Chalk, the base of the Lower Greensand, and the base of the Weald Clay. α marks the point where the Ironsands of the Sandgate Beds thin out and β the position of the lateral change of facies in the Hythe Beds.

Anticlines: A = Farleigh Wallop; B = Pease Marsh; C = Elstead; D = Medstead; D′ = Hindhead; E = Winchester; F = Vale of Warnford; F′ = East Meon; G = Fernhurst; H = Crowborough; J = Haywards Heath; K = Greenhurst; L = Dean Valley.

Synclines: *a* = Church Oakley; *b* = Horsedown Common; *c* = Albury Park; *d* = Blackheath; *e* = Binstead; *e′* = Thursley; *f* = Alresford; *f′* = Haslemere; *g* = Kilmeston; *h* = Cuckfield; *j* = Henfield.

southwards evidence of comparable movement is not to hand, but this is partly due to the absence of sufficient exposures for demonstration and more particularly to the fact that these minor movements would only affect sedimentation in the more littoral (northern)

zone. The actual amount of movement in each case is very slight and would not be sufficient to affect sedimentation in the deeper water areas of S. Surrey and Sussex. There is, however, evidence of an important contemporaneous syncline of N.N.W.–S.S.E. trend, running through Puttenham and Highdown Ball, for the Puttenham Beds after appearing from beneath the Folkestone Sands at Compton, thicken rapidly westwards and at Church Croft, 2½ miles S.W. of Compton, are at least 110 feet in thickness (4, p. 31). Five miles farther westwards along the same line of strike they have diminished at Farnham to 17 feet (4, p. 156). When traced southwards from this line, they are seen to be 30 feet thick at Munstead Heath (4, p. 31), 125 feet at Highdown Ball (12), 2 miles to the S.S.W., about 90 feet thick under Rodborough Hill, near Milford, and they are about 40 feet between Witley and Thursley and from thence thicken slightly westwards.

It has not proved possible to trace the effects of these pene-contemporaneous folds into the Folkestone Sands, for the absence of definite and easily recognizable horizons renders structural work exceedingly difficult and, in addition, the available sections and well records leave much to be desired. The sum of the evidence, however, shows that subsidence of the central regions of the geosyncline had now ceased, for the beds reach their maximum thickness of about 250 feet in the N.W. corner of the Weald and decrease steadily in thickness when traced eastwards and southwards from this point.

4. The Effects of Pressure on the Wealden Geosyncline.

In the early years of the last century both Martin (13) and Sir Charles Lyell (14) recognized that the Wealden area is crossed by two sets of structural lines at right angles. Their views as to the nature of the transverse structure cannot be entertained to-day, but it must be emphasized that such a structural pattern is the inevitable result of the longitudinal and the transverse stresses set up by the contraction of the Wealden geosyncline. Attention in recent years has, however, been concentrated mainly on the more easily decipherable strike folds and faults and the importance of the transverse tectonic lines has been rather overlooked. It is hoped that the evidence of the preceding pages will enable a somewhat clearer view to be obtained of the relative importance and the growth of the two sets of fractures in the Western Weald.

The long continued down-warping or sedimentation subsidence of the central parts of the Wealden geosyncline drew to an end during the deposition of the Hythe Beds. Then followed the slow contraction of the whole area. In the E.–W. folds to the south of Godalming (p. 261) we see the first responses to the N.–S. pressure, whilst at a slightly later date the N.–S. axes of warping of pre-Folkestone Sand age represent the beginning of the transverse

contraction. The Upper Cretaceous beds have unfortunately been removed from the Weald proper, but my friend Mr. D. L. Linton, in some very important but as yet unpublished work, has shown that there was considerable movement during the deposition of these beds in the immediately adjacent areas, and therefore it seems reasonable to infer that the folding was still slowly proceeding in the adjacent Wealden tract. Since that time the area has been almost entirely a land area and we have no record of earth movement until we reach the Middle Tertiary period of orogenesis. The effects of this period of folding were so important that it has seemed desirable to prepare a special map of the mid-Tertiary structures (Fig. 6). The structural lines in the adjacent Chalk areas have been taken from Mr. Linton's map (15), whilst for the remaining Lower Cretaceous areas the tectonic lines recognized by H.M. Geological Survey have been supplemented by the author's own observations. Study of the map will show that the area is crossed by a large number of arcuate strike folds, arranged roughly *en échelon* and locally passing into faults. The effects of the E.–W. contraction are clearly visible in the form of monoclines and fault lines, whilst there is also a certain amount of gentle transverse folding (4, p. 10) which has, however, been omitted from the diagram for the sake of clarity. It is to be noted that there is evidence of a connexion between the Tertiary folds and the tectonic lines of Lower Cretaceous date. For example, the contemporaneous anticline and syncline of the Godalming neighbourhood (see Fig. 3) are to-day clearly visible in the landscape owing to their accentuation in Tertiary times. It is also noteworthy that in both Lower Cretaceous and Tertiary times the most disturbed part of the area lay near the line of the Hog's Back. The effects of the monoclines, which actually run slightly west of north and east of south, have been to divide the Lower Greensand terrain into a series of blocks, each of which have been twisted slightly towards the west, as is shown by the fact that the generalized contours on the dip slope do not follow the E.–W. regional strike, but run in a W.S.W.–E.N.E. direction.

Tectonic movement has not apparently completely ceased in the area, for it is to be noted that the majority of the earthquakes in the Weald have occurred along the Lower Greensand belt (16) and thus it is plain that the Weald is another of those areas whose tectonic history is much more involved and continuous than was once thought to be the case.

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The Conglomerates of Allt Goch and Mathrafal-ffridd (Montgomeryshire).

By John I. Platt, M.Sc., F.G.S.

THE following is a description of the conglomerates which crop out at Allt Goch and Mathrafal-ffridd near Meifod (Montgomeryshire) and which were examined on the suggestion of Professor W. B. R. King. Allt Goch is about 4 miles north of Mathrafal-ffridd, and the two localities lie on opposite flanks of the anticlinal structure which passes through Pont Robert and which brings up Ashgillian and Caradocian rocks. The conglomerates themselves are at, or near, the base of the Valentian. At other places in the neighbourhood the basal member of the Silurian consists of coarse deposits (sandstones, etc.), but "they very probably do not represent the lowest zones that are found in Central Wales" (1).[1]

Professor King refers to these conglomerates in the Oswestry district memoir of the Geological Survey (1929) where, describing the Llandovery facies of the Valentian, he writes :—

"At the base a massive greenish grit (with a basal calcareous conglomerate) occurs at Allt Goch (4)."

"The conglomerate consists of pebbles of clear quartz up to three-quarters of an inch in diameter and smaller pebbles of various igneous rocks set in a calcite cement with numerous

[1] The numbers in parentheses refer to the References at the end of the article.

well-preserved specimens of a favositid coral and a few poorly preserved brachiopods (5)."

The Mathrafal-ffrîdd rock is referred to in the paper on the "Geology of the district around Meifod", p. 686 (2).

The exposure at Allt Goch is at present being quarried and it was therefore easy to obtain a representative collection of the included pebbles. The rock itself is a greyish-white grit with a high calcareous content and portions only of it, chiefly near the base, are conglomeratic. The conglomerate of Mathrafal-ffrîdd is poorly exposed on a steep slope covered with dense plant growth. It is less calcareous than at Allt Goch, and the pebbles within it are smaller, very few exceeding half an inch in diameter. A number of pebbles were obtained from a large boulder of conglomerate near to the Mathrafal-ffrîdd exposure and beyond doubt of the same rock.

There appears to be no striking difference between the pebbles from each locality, and therefore they will be described together.

In addition to the usual pebbles of quartz, vein quartz and quartzite, the conglomerates contain pebbles of shale, mudstone, slate and grit, as well as specimens of derived calcareous rocks and phosphatic concretions. The latter are well rounded and, at Allt Goch, as large as half an inch in diameter, but smaller at Mathrafal-ffrîdd. They are composed of an agglomeration of broken organic remains and are certainly of local origin, for they are too unstable to withstand transportation for but very short distances. Professor King describes their occurrence at Craig Wen quarry (2 miles south-west of Mathrafal-ffrîdd), as follows:—

> "Among the mudstones of the highest Ashgillian beds are dark phosphatic nodules . . . A concentration of nodules may be seen in the mudstones immediately below the bottom of some of the sandstone-filled troughs, suggesting that the fine mud has been washed away and the larger phosphatized fragments left behind as a concentrate at the bottom of the hollows (3)."

The igneous rocks among the pebbles have received the closest attention. Of these none other than volcanic and pyroclastic types were found, and of the former several varieties were recognized, viz. rhyolites, keratophyres, andesites and spilites; but the acid rocks far outnumbered those of intermediate basic composition.

The rhyolites consist almost entirely of quartz and an albitic plagioclase felspar. Considerable variations in texture occur, and it was found possible to distinguish between various types according to the texture and the relative proportions of the quartz and felspar present. No wholly glassy varieties were found.

Most of the rhyolites contain phenocrysts, although the concentration varies very much. In a large number the ground-mass consists of a cryptographic intergrowth of the constituent quartz and felspar, but in others a tendency to a linear arrangement is

superimposed upon the normal texture, this being caused by the occurrence of minute laths of felspar. Other rhyolites show flow texture which is indicated by bands of different grain-size seen under crossed nicols or by the occurrence of ferruginous material and, in two specimens, of chlorite. In others the alinement of the felspar laths and of the phenocrysts is also due to movement during consolidation. Some rhyolites are devitrified, the original texture being indicated by differently coloured bands, etc., when seen in ordinary light. A few specimens show a tendency to spherulitic texture, revealed by a black cross (never very good) when seen under crossed nicols.

The porphyritic rhyolites contain phenocrysts of quartz and felspar. The former are not as important as the felspars and never show good shapes, but are rounded and intergrown along their margins with the cryptographic ground-mass, portions of which are incorporated within the crystals themselves. They also contain "irregular" inclusions of fluid lacunae, with gas bubbles, often arranged in streams.

The felspars are all plagioclase and show polysynthetic twinning, the bands being very narrow. The twinning is after the albite or the pericline laws, but twinning after both laws was seen in the same individual in a few crystals. Two phenocrysts (in slides Nos. 41 and 43) are of special interest. They show very narrow twinning bands which wedge out in both directions and give an appearance similar to that of microcline under crossed nicols. The phenocrysts may be microcline-perthite. The plagioclase felspars have a maximum extinction angle upon symmetrical sections of 15° and a refractive index slightly lower than that of the Canada balsam of the slides, so that the composition of the mineral is approximately $Ab_{95}An_5$. Only a few of the phenocrysts are quite fresh, many of them are saussuritized and a few partially or wholly replaced by calcite.

Chlorite after biotite occurs in some slides and in one (No. 43) took up a large part of the rock. Ilmenite, invariably changed to leucoxene, also occurs as well as pyrite.

In a few of the rhyolites quartz plays a very minor part, occurring only in the ground-mass and never as phenocrysts. These show close affinities to the keratophyres.

In hand specimen the keratophyres are fine-grained and pale green in colour, while examination under the microscope reveals the presence of small phenocrysts set in a ground-mass almost wholly composed of minute laths of plagioclase felspar. The felspar laths give a trachytic texture to the ground-mass and show single or polysynthetic twinning with a maximum extinction angle upon symmetrical sections of 13° and a refractive index very little different from that of the balsam, their composition being therefore $Ab_{90}An_{10}$.

No phenocrysts quite similar to the "microcline-perthite" of the

rhyolites were seen, but it is probable that some would be found if more material were available.

The felspar phenocrysts differ only in size from the felspars of the ground-mass. In these slides there is an increase in chlorite, which always appears as a pseudomorph after biotite, and makes up quite one-fifth of the rock. A little ilmenite, changed to leucoxene, also occurs.

Three small pebbles of a more basic lava were cut. They are very rich in felspar, both in the ground-mass, which shows variolitic texture, and as small rectangular phenocrysts. The whole rock is very dark, which is due in part to the occurrence of minute grains of magnetite and limonite disseminated throughout the rock and to the partial saussuritization of the felspars. The rock is also vesicular and contains small pseudomorphs of serpentine after olivine. Owing to the state of preservation of the felspars it is not possible to determine their original composition, but they probably do not differ much from those of the more acid lavas. The rock is a more basic member of the same suite and is a spilite.

Two pebbles of andesites were cut. Seen under the microscope these are not very different from the keratophyres in general appearance. In one the ground-mass is nearly as dark as in the spilite, but shows trachytic texture, while the other specimen has a much lighter ground-mass which is not so clearly trachytic. The phenocrysts are all plagioclase showing polysynthetic twinning, but are stumpy and rectangular in shape while many show dome faces bevelling the corners. The felspars have a maximum extinction angle upon symmetrically cut sections of 11°, but the refractive index is higher than that of the Canada balsam, so that the mineral is andesine ($Ab_{70}An_{30}$). Decomposition has proceeded in such a way in some of the crystals as to indicate the presence of zoning in the original crystal. Limonite, magnetite (secondary), and leucoxene are also present, while there are one or two pseudomorphs of chlorite, some if not all of which have replaced felspars.

A few pebbles of pyroclastic rocks were cut, but these are not very common. All that were examined were fine-grained, some showing bedding. The constituent fragments of these rocks are rhyolite or keratophyre, but no more basic types were seen.

In the field the conglomerates are replaced along the strike by grits, calcareous sandstones, and concretionary sandstones. The outcrops are not very large, and their occurrence suggests that their original extent was limited to a small area and further that a number of the constituent pebbles have been derived from a source or sources at no great distance from their present location. The occurrence of pebbles of grit, shale, slate, limestone and phosphatic nodules further strengthens this assumption.

A probable source of some of the igneous rocks may be the Ordovician lavas, ashes, etc., of the Berwyn country to the north and north-west if these latter rocks were exposed during Basal

Valentian times. Rocks of similar types to these ashes, lavas, etc., occur among the pebbles, but so far it has not been possible to match any of the specimens. Some of the rhyolites may also have been derived, either directly or indirectly, from older rocks. The keratophyres among the pebbles are quite different from those of Glyn Ceiriog (7 miles to the north-east), the age of which intrusion is given tentatively as Devonian (6).

Comparing the pebbles with those found in the conglomerates near the Ordovician-Silurian boundary between Rhayader and Llansawel (7), it was noticed that the rhyolites as a whole are not very different, a few being quite indistinguishable, while some described here were not found in the district farther south. The keratophyres differ essentially from those obtained from the rocks farther south, in that they contain a large quantity of chlorite after biotite. Although careful search was made no plutonic rocks were found.

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(2) Ibid., 686.
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(5) Ibid., 73.
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An Olivine-Bearing Conglomerate from the Island of Raasay, Inverness-shire.

By Charles F. Davidson, University College, Dundee.

In his posthumous paper on the geology of the Island of Raasay H. B. Woodward (1) [1] remarks: "On the fore-shore south of Oskaig Point, the modern beach is cemented into a conglomerate." The unique mineralogical composition of this conglomerate, which has been collected in the course of a study of the Tertiary igneous rocks of Raasay and neighbouring islands, warrants the following note.

The rock occurs in a small bay below the wooded cliffs of Cnoc-a-Ra on the west coast of the island. To the north and east lies an intrusion of felsite, granophyre and granite, while immediately surrounding the conglomerate is a great sill of crinanite, teschenite and picrite, some 400 feet thick, the differentiation of which is under study. The deposit under consideration is in parts about 5 feet thick, and rests on the picritic wave-cut platform of this sill.

In the hand specimen the rock is seen to be entirely composed of smooth pebbles of basalt, crinanite, teschenite, picrite and rarely

[1] Figures in parentheses refer to References at end of article.

granophyre, sparsely scattered in a coarse, sandy ground-mass. This consists principally of rounded grains of olivine, with some augite, felspar and iron ore, in an obscure white matrix, seen in thin section to be formed of minute interlocking laths of authigenic calcite, with rarer zeolitic and serpentinous areas. The mineral

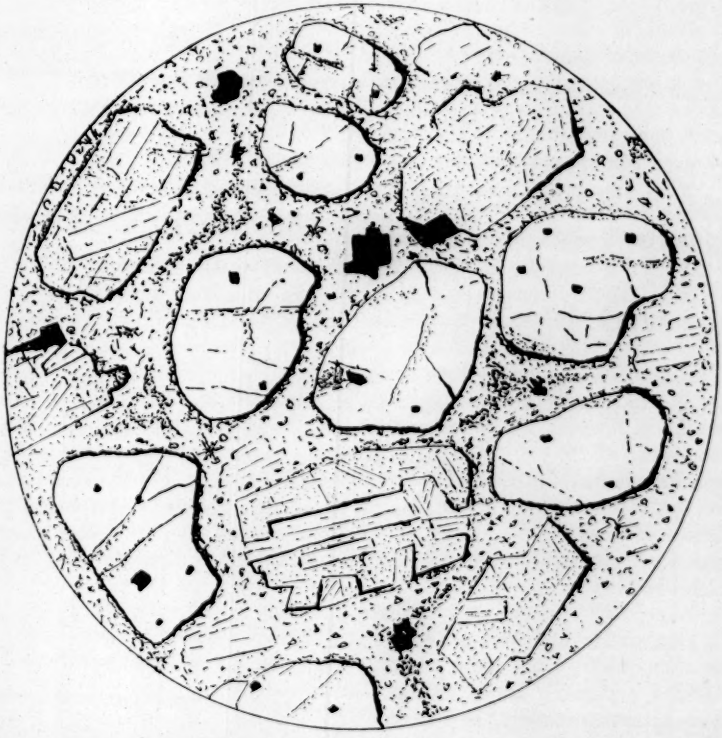

FIG. 1.—Micrograph of average sandy area of conglomerate from Oskaig, Raasay, showing rounded grains of olivine, ophitic augites, iron ores, and occasional felspars, in a calcium carbonate matrix. (× 30.)

composition (percentage weight) of the sandy areas has been averaged by a Shand micrometer as follows :—

	%
Olivine	29·5
Augite	24·5
Felspar	23
Iron ores . . .	3
Calcite and zeolitic matrix	20

In thin section, therefore, this rock might be mistaken for a picrite if given but a passing glance.

From considerations of space no detailed description of the component detrital minerals will be given, as they differ in no appreciable way from the minerals of the near-by igneous rocks, types common in the northern Hebrides. It may be noted, however, that the olivine is optically negative, optic angle nearly 90°, and refractive index 1·695±·005; many inclusions of small opaque spinellids are evident. The augite is partly a colourless variety and partly a pleochroic titanaugite, while grains of a deep grass-green aegirine-augite have been observed. Basic labradorite and bytownite form the most abundant felspars, and are apparently derived from the ultrabasic modifications of the differentiated crinanite sill; rarely, however, grains of a potash felspar derived from the acid sill are seen, sometimes in micrographic intergrowth with quartz.

Other minerals occurring are serpentine, magnetite, ilmenite, limonite, leucoxene, quartz, sericite and calcite. The average grain-size is 0·8 mm.

Dr. F. Walker (2) has recently remarked on the relative stability of the olivine characterizing the basic and ultrabasic Tertiary igneous rocks of the Hebrides, and striking examples of this phenomenon are seen in the island of Raasay. The picritic floor of the Oskaig sill is, like the floor of the Shiant Isles sill, a bright green rock which may be powdered to a sand between the fingers, and which in slice shows decomposition of all components except olivine and augite, the former being frequently quite fresh. Such crumbly picrites have contributed very markedly to the mineral content of the olivine sands, examples of which are also found in western Raasay, closely resembling the Duntulm sand (2), but somewhat poorer in ferromagnesians owing to contamination by detritus from acid intrusions.

The conglomerate just described, which is the only example of a consolidated olivine-bearing sedimentary deposit known to the author, yields even more striking evidence of the stability of these olivine crystals. Here, although always well rounded and subject throughout considerable periods to hydration and alteration processes by immersion in sea water, they show not the slightest trace of decomposition.

The writer acknowledges his indebtedness to Dr. F. Walker for specimens of the Duntulm (Skye) sand, and for discussion of the questions involved by these deposits.

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The Fish Bed in the Denbighshire Coalfield.

By Henry H. Simpson, B.Sc., A.M.Inst.C.E.

THE records of fossil fishes in the Denbighshire Coalfield appear even more scanty than those of the molluscs, and one of the first references [1] is to a fish-bed in the roof of the "Queen Coal" at Llay Hall Colliery in the north of Denbighshire. This coal is 300–400 feet from the bottom of the Middle Coal Measures, and is known as the "Premier" in Flintshire, and in South Denbighshire as the "Wall and Bench". Throughout Denbighshire it is the lowest generally worked seam of the productive measures, as the coals below it are few and, in any case, too thin for profitable operation, except when in association with pottery clay.

The fossiliferous seam is about 6 inches above the coal, is less than $\frac{1}{8}$ in. thick, and, when freshly exposed, is quite black, the surface being almost completely covered by a fragmental deposit of bones, scales, teeth, and spines, and must represent a considerable period during which there was little or no deposition of shale. On weathering, it exhibits a collection of white and bluish-white fragments on a black bituminous shale, which is very readily picked out on a coal tip.

Samples of this have been collected from the waste in the south, at Hafod-y-bwch, Vauxhall, Wynnstay, and Bryn-yr-owen collieries, and at an exposure of the "Wall and Bench" near Ruabon good specimens of the bed have been obtained in situ. In collieries where "Wall and Bench" is not worked, e.g. Bersham and Plas Power, no sign of the bed was seen on the tips.

There appears to be no doubt that the persistent fish-bed above the "Premier" (of Flint) is continuous from north to south Denbighshire, and points to a similarity of conditions during the early part of Middle Coal Measure times in both the Flint and Denbighshire coalfields. In this bed, and scattered through the black shales, the following specimens have been collected [2]:—

Palatal teeth .	*Pleuroplox rankinii.*
Scales . . .	*Rhizodopsis sauroides.*
Teeth and scales	*Megalichthys.*
Scales . . .	*Caelacanthus.*

A comparison of the plotted sections has co-related the "Queen" of the north to the "Wall and Bench" of the south, but the presence of the fish-bed confirms this conclusion.

[1] *The Geology of the Country around Wrexham*, ii, 37–42. Geological Survey Memoir.

[2] The specimens have been identified by the Geological Survey.

REVIEWS.

METAMORPHISM. A Study of the Transformations of Rock Masses. By ALFRED HARKER. pp. ix + 360, with 185 figures. London: Methuen and Co., Ltd., 1932. Price 17*s.* 6*d.*

THE study of metamorphic rocks embraces a very extensive field. Every kind of sedimentary or igneous rock may be considered to have a representative in the metamorphic class; and as there are many stages or degrees of metamorphism, each of which may conceivably be entitled to a separate nomenclature, the number of possible varieties or species may become very great. On the whole, students of geology in the Universities are not called on to acquire a very profound knowledge of these; a few examples of the commonest types are familiar to all, but the detailed study demands an expenditure of time and labour which is beyond the reach of the ordinary student. The subject, however, especially when taken in close association with regional and tectonic investigations possesses great fascination. Much work has been done in this field by British geologists and a general account of the subject has become a great desideratum. Dr. Harker's book in consequence is very welcome and, as it meets the existing need in a manner and to a degree fulfilled by no other text book, it is destined to hold a high place in the literature of petrology.

There are several possible ways of approaching the subject. The most obvious is to undertake a classification and description of the prevailing types according to their abundance, importance, or interest. This method the author avoids, his object being essentially to discuss and illustrate the fundamental principles according to which, in his opinion, the transformation of the rocks is carried out. There is abundance of illustration by typical examples, mostly from British metamorphic provinces, and well exemplified in numerous drawings. No well-characterized class is omitted from his review, but the underlying framework is philosophical, being constructed on the physical principles that determine the transitions. These principles are essentially those of heterogeneous equilibrium. A rock mass of given chemical composition being subjected to certain conditions of temperature, pressure, and stress will pass through a series of changes, each of which is characteristic, and the process may be traced from stage to stage, if the sequence of reactions is understood.

The opening chapters are devoted to contact or thermal metamorphism, regarded as due to rise of temperature without important increase of pressure or of stress. The treatment is brief but sufficient. It is easy to find examples of rock types which can be followed from unaltered facies to complete reconstitution and

recrystallization, and the agency in operation is never in doubt. There is consequently little room for differences in opinion, though the variety of the phenomena is very great. This is followed by a chapter on pneumatolysis and metasomatism, excellent but all too short. A characteristic type such as topaz-fels, for example, deserves mention, and also the well-established pneumatolytic origin of many asbestos deposits. This subject, however, especially in connection with the origin of ore-bodies, would require a separate treatise. The extensive transfusion of soda and its compounds around intrusions receives notice, but the extravagant claims made by some petrographers are regarded with suspicion.

The remainder (nearly two-thirds) of the book treats of the reconstitution of rocks due to regional metamorphism or, as it may be defined, reconstruction under stress, with rise of pressure and temperature. After an elementary discussion of the principles of stress, and the development of cleavage and crush-structures (dynamic metamorphism), the origin of crystalline schists and gneisses as exhibited on a large scale in many metamorphic provinces is discussed. Minerals are divided into two groups, the stress and anti-stress, and the process of building up a well-crystallized schist or gneiss is discussed with the description of typical instances. Rise of temperature is regarded as the dominating factor, though rise of pressure and of stress, concurrently, are of great importance. A wealth of details is given, usually from British rocks, and sufficient though by no means complete references to the literature.

These chapters may be recommended without hesitation to the careful study of all students of petrology. They are full of interest and novelty and present a very comprehensive and unbiassed account of the subject. The tone, on the whole, is didactic and expository, and perhaps it would not be difficult for an experienced worker on metamorphic rocks to provide an exception to almost every rule that is laid down. So vast is the field and so varied are its phenomena that it is impossible to exhaust the material. Yet the author is to be congratulated on the breadth of treatment and the philosophic description of the problems involved. The various "rules" or "laws" that have been adduced to explain the metamorphic process are passed in review. Each of these is valid up to a certain point, but in itself incomplete. We have, for example, the "volume law", which fails conspicuously when severely applied. There is also the hypothesis of "depth zones", very good so far as it goes if the necessary assumptions are made. The application of the "phase rule" also is subject to obvious limitations; and the question of "equilibrium" is many-sided and obscure. Experimental evidence is almost wholly lacking, and "Riecke's principle" is little but a hypothesis. Even the laws of "stress" fail when the material is deformed beyond its elastic limit and plastic flow begins, as is probably almost universally the case. The author's handling of these debatable questions is admirable.

Much attention is given to the study of the rocks of the Southern Highlands of Scotland. Various zones of metamorphism are laid down, following closely the pioneer work of Barrow in this district. The areas of most intense metamorphism characterized by development of sillimanite are regarded as due to intense original metamorphism. Barrow regarded them as produced by the " older " granites. Unfortunately the evidence is obscure, and in part contradictory, as much " older " granite is practically universally present where the sillimanite rocks abound. There are other parts of the Highlands, however, e.g. the Findhorn valley, where these complications seem to be absent. A point of some interest also is that Barrow held that the succession of these rocks was upwards from the Highland Border, in a north-west ascending series. In that event the undermost rocks are those that are least metamorphosed. The subject is intensely controversial, but there can be no doubt that Dr. Harker has given a clear and logical account of his interpretation of the phenomena. Whether it is complete or final the future alone can judge. It seems probable that the best ground for the study of progressive and digressive metamorphism is in Shetland.

The most important criticism that can be directed against this treatise is that chemical analyses of the rocks under discussion are entirely lacking. The composition of the rocks is an essential factor in the problem of metamorphic changes. Such minerals, for example, as andalusite, ottrelite, and staurolite, are probably restricted to rocks having fairly definite chemical characteristics. Yet, for this lacuna the author is hardly to be blamed. Our knowledge of the chemistry of British schists and gneisses is as yet far too imperfect to serve as a basis for adequate discussions. We anticipate, in fact, that the result of Dr. Harker's work will be the stimulation of the study of British metamorphic rocks both in their mineralogical and in their chemical relations. It certainly fills an important place in the literature of petrology, and in lucidity, balance, and breadth of view can serve as a model to all future writers on the anatomy and history of rocks.

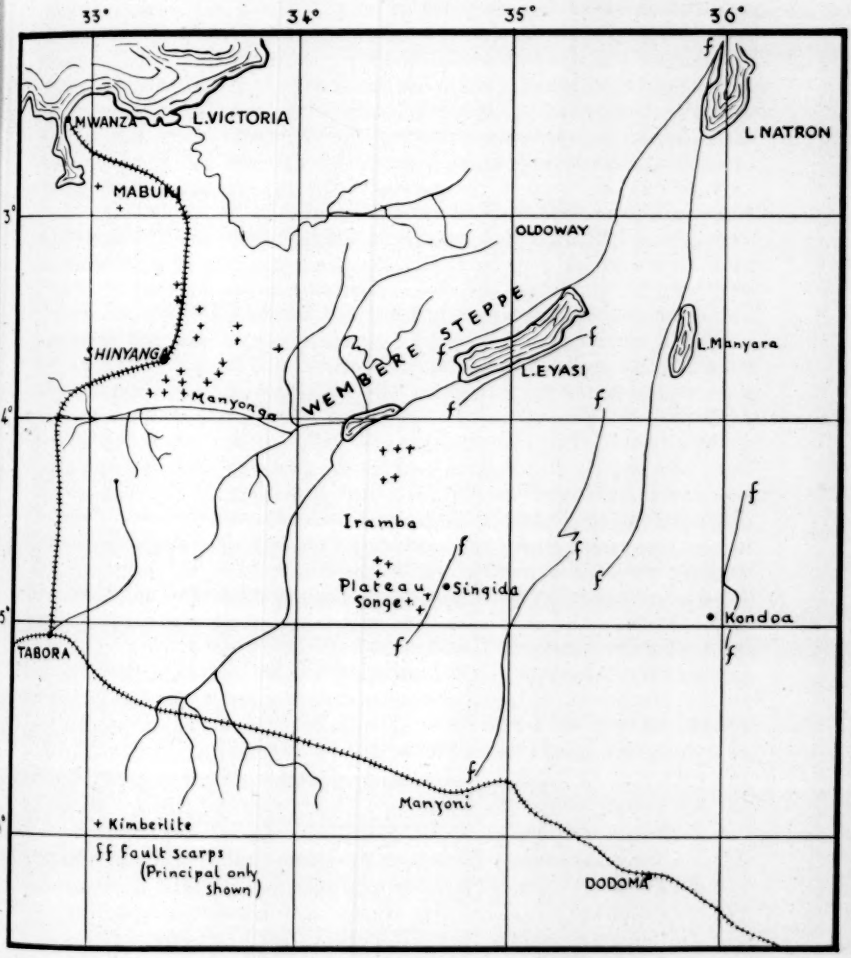
J. S. F.

SHINYANGA DIAMOND FIELDS : GEOL. SUR. DEPART., TANGANYIKA TERRITORY. E. O. TEALE. Short Paper No. 9, pp. 35, Maps. Dar es Salaam, 1931. Price 4*s*.

THE KIMBERLITE AND ASSOCIATED OCCURRENCES OF THE IRAMBA PLATEAU. E. O. TEALE. Short Paper No. 10, pp. 7, Map. Price 2*s*.

IN these two short papers is available an account of almost all that is known of the diamond-fields lying between Mwanza and Dodoma, in North-West Tanganyika Territory. First reported before the war from Mabuki, where stones of excellent quality were

found, the diamondiferous area was extended in 1926 by the discovery of the Shinyanga field and some four years later by the location of at least eleven occurrences of kimberlite on the Iramba Plateau. About nineteen pipes are known from Shinyanga, probably many more exist. Except for the history of the detrital deposits,



Sketch Map of N.W. Tanganyika Territory.

the geology of the district is simple; a non-foliated or slightly streaky granite has invaded and metamorphosed a system of ancient sediments, lavas, and tuffs. These are cut by veins of pegmatite and aplite, by dykes of fresh dolerite, and by the diamondiferous

kimberlite. " The Detrital Deposits are very widely spread over a vast portion of the peneplain area of the interior," and consist of old river sediments, " cement "—a quartz sand cemented by clay, silcrete, jasper, and cherts with impressions of leaves.

They are believed to be relics of the drainage belonging to the period of the 4,000 ft. peneplain which preceded the present erosion cycle. These river systems were finally broken up by the pre-Pleistocene and probably Middle Tertiary movements originating the trough faulting in the neighbourhood of Lake Eyasi and Manyoni.

In Pleistocene time Shinyanga stood on the north-west margin of the sheet of water then occupying the Eyasi-Wembere basin continuous with the larger Lake Victoria of that period. Evidences of its existence are seen in the extensive fluvio-lacustrine beds in the Manyonga area. The economic importance lies in the probability that a reversal of drainage has taken place as a result of these pre-Rift movements which dislocated the old peneplain topography, and in searching for diamonds and their origin this has to be kept in mind. The diamonds at Mabuki and Shinyanga are found " in a relatively shallow secondary deposit " and " strong reasons " are produced for believing the bulk of the gems are derived not from the kimberlite pipes in the vicinity but from an additional and undiscovered source. At Mabuki the proportion of diamonds in the gravels and the yellow ground derived from the pipes is as 10 to 1, a possible concentration, but the relative distribution and content of the ilmenite in both, its composition and occasional worn appearance, together with differences in the character of the associated garnets and the presence in the gravels of rock fragments not found in the neighbourhood, suggest an outside source for the diamonds. The opinions of Dr. du Toit are freely quoted, and Dr. Teale emphasizes the obscurity of some points and pleads for further detailed observation, especially indicating the " cement " and what may lie beneath, to the future prospector. Washings of the kimberlite on the Iramba Plateau have so far proved unproductive, two diamonds only, from the Songeli region, having been reported. The occurrence of the kimberlite in this area as sills or sheets, due to the tabular nature of the granite into which it is intrusive, is worthy of note.

J. P.

PALÄOGEOGRAPHISCHE UNTERSUCHUNGEN ÜBER DEN OBEREN BRAUNEN UND UNTEREN WEISSEN JURA NORDWESTDEUTSCHLANDS. By W. SCHOTT. Inaugural-Dissertation, Göttingen ; *Abhandlung der Preuss. Geol. Landesanstalt*, N.F., Heft 133, 1932.

THIS thesis raises an issue of intimate concern to British geologists : the existence of land throughout Upper and part of Middle Jurassic times over the greater part of the North Sea. The author shows that the clastic sediments increase in thickness and in grade

towards the north in all the Upper Jurassic formations of north-west Germany, thus indicating a northerly derivation from the North Sea region. Southwards all the sandstones become thinner or disappear entirely, passing laterally into clays. The influence of the London–Ardennes Island, with its continuation, the Rhenish Schiefergebirge, seems to have played an almost negligible part in supplying sediment to the north-east. It might perhaps be suggested that the slope of its surface was towards the west or north-west, for it contributed sands to the English Midlands at least in Inferior Oolite and Corallian and probably Kimeridge and Portland times. The existence of the island is demonstrated, just as off the opposite coast in Kent and the environs of London, by the rapid diminution of the formations towards its shores.

Linking his results to those obtained by Brinkmann farther east, along the Southern Baltic coast, Schott concludes that the Middle and Upper Jurassic Sea of north Germany lay south of a large land-mass—Fennoscandia—undergoing active erosion. For the Bathonian period he visualizes the coast as crossing Holland and the North Sea from the Zuider Zee to the Wash, and thence curving through Lincolnshire to Edinburgh, Inverness, and Orkney. Presumably this line is only diagrammatically entered upon the sketch-map; but the English and Scottish part of its course is certainly drawn too far to the west. In succeeding periods he shows the coastline as retreating progressively eastwards from Britain and northwards from Germany, while a gulf develops over Denmark, cutting off a promontory of Fennoscandia which he calls Cimbria.

Perhaps the most interesting result of the work is to bring out that the Jurassic rocks of north-west Germany were deposited in a geosynclinal trough between the Fennoscandian mainland on the one hand and the London–Ardennes island on the other, closely comparable with the troughs of England. The Osnabrück Strait, as Schott calls this trough, strikes N.W.–S.E. and joined up the English Midlands with the sea over Central Germany and the rest of Europe. The analogy with Britain does not stop here, for the Osnabrück trough was crossed at right-angles by two axes of uplift—the Osterkappeln-Hagen Schwelle and the Bergkirchen-Bielefeld Schwelle—which caused retarded and interrupted deposition just as did the Market Weighton, Vale of Moreton, Mendip, and other axes.

During the Mesozoic era these axes or Schwellen seem to have been a universal feature of the troughs and "dish" seas of both the labile and the stable parts of the European shelf. They have their analogues in the Wälle of the Russian Plain, described by Von Bubnoff: long and slightly sinuous ridges of contemporaneous uplift, which ramble like huge caterpillars or giant eskers across the otherwise unbroken monotony of the map of Russia in Europe. From Schott's account of the stratigraphy and the accompanying graphic coloured table, it is evident that, as in England, the uprise (or relative stability) of the axes of uplift was independent of the general subsidence of the

troughs and presumed compensating elevation of the intervening horsts. Although he seems to regard both classes of movements as epeirogenic, the former was more probably a mild orogenic process. Von Bubnoff is of the opinion that the uprise of the Russian "Wälle" should be classed as a gentle manifestation of orogenic forces, and in England all the axes can be seen to coincide with lines of earlier uplifts of undoubtedly orogenic, generally Armorican, or Charnian, origin.

In the sphere of palaeontology the author is obviously not at home; otherwise he would have felt bound to sift the heterogeneous list of ammonites recorded from the so-called "Cornbrash". The retention of this word in north-west Germany with its present meaning is unjustifiable and Schott wisely discards it in his stratal table, although he continues to use it throughout the paper. It is absurd to apply the name to a series of strata yielding *Parkinsonids* and extending apparently from the top of the Great Oolite series to the base of the Upper Inferior Oolite. Moreover, the only feature common to the true Cornbrash and the north-west German strata—namely, the zone of *Macrocephalites macrocephalus*—is outside the German "Cornbrash" and classed with the overlying clays; notwithstanding, *Cadoceras sublaeve* (Sow.) (a typical Kellaways Rock fossil) is recorded in two places from the Cornbrash.

Regional studies such as these, with the new tectonic orientation so largely inspired by the labours of Professor Hans Stille, bring us nearer the realization of many attractive inductions.

W. J. Arkell.

The Form and Properties of Crystals. An Introduction to the Study of Minerals and the Use of the Petrological Microscope. By A. B. Dale. pp. x + 186; [2], with 122 text-figures. Cambridge: University Press, 1932. Price 6*s*. net.

This little book aims at giving to students of petrology a simple, short, and inexpensive introduction to crystallography and the other physical properties of crystals. The authoress has set herself a difficult task, for it is not easy in presenting the subjects covered in this book to achieve both brevity and simplicity. The extent to which she has been successful must be judged by the students for whom the book is intended rather than by those already familiar with the subject matter and with the many larger text-books which are available.

The treatment of crystallography occupies 71 pages (Chapters I and II). There is a short chapter on the internal structure of crystals, and another on their general physical properties—in which is included twinning as well as cleavage, fracture, parting, colour, streak, lustre, hardness, and specific gravity. Finally there are two chapters on the optical properties and on the method of investigating them.

With the exception of the last chapter the book is clearly written and the treatment is adequate for the purpose if it can be supplemented by lectures and practical work. This applies particularly to the description of the use of the goniometer, the drawing of crystals, and the construction of stereographic projections. The figures given of crystal-forms are, on the whole, clear, but not always accurate.

The Becke Line method of determining relative refractive indices in thin sections is described and well explained, but it is not made clear that it is equally applicable to grains or cleavage fragments in liquids for which the Schroeder van der Kolk method is recommended. Again the explanation of extinction-positions is admirable, but too little space is devoted to description of its measurement, the very important felspars being dismissed in a few lines, and the student is led to believe that all sections of twin crystals give symmetrical extinction if the twin-plane and composition-plane coincide. The description of phenomena in convergent light is written from the point of view of orientated thick sections of minerals, and is not very helpful as a guide to the phenomena as observed in rock-sections.

W. C. S.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

23rd March.

Dr. L. J. Spencer : " Biographical notices of mineralogists recently deceased (Fifth Series)."

Mr. Max H. Hey : " A possible source of error in the determination of symmetry from optical extinction-angles."

In certain cases a small departure of a cut plate from the intended section direction may lead to comparatively large errors in the extinction-angle and hence to an incorrect determination of symmetry. This is well illustrated by mesolite.

Mr. Max H. Hey : " Studies on the Zeolites. Part V.—Mesolite."

New analyses and X-ray studies of mesolite indicate that the correct formula is $Na_4Ca_6Al_{16}Si_{24}O_{80}.22H_2O$. There is often a slight replacement of Na by K, and generally an appreciable replacement of Ca by 2Na. The axial ratio has been determined by goniometric and X-ray methods. Refractive index, birefringence and optical axial angle measurements have been made. The vapour pressure has been studied by the isohydric method previously described. A number of base exchange products have been prepared and the potassium and lithium derivatives shown to be identical with those obtained from natrolite. This provides the first conclusive proof that mesolite and natrolite

are, as has been commonly assumed, isostructural. X-ray photographs of mesolite are very similar to those of natrolite, but show distinct differences. The space-group is C_2.

Dr. A. E. Mourant: "The dehydration of thomsonite."

A study of the dehydration of thomsonite by the isobaric method. The results, obtained some years ago, are supplementary to those obtained by Hey by the isohydric method and differ from them in some respects. Dehydrated thomsonite does not absorb air. The lattice-shrinkage reaction has been further investigated.

Mr. F. J. Turner: "Note on the occurrence of piedmontite in quartz-muscovite-schist from the Shotover valley, Western Otago, New Zealand."

The description of piedmontite in schist occurring as boulders in the Shotover River. The mineral has not previously been recorded from New Zealand.

CORRESPONDENCE.

THE BEACHES OF GOWER.

SIR,—I should be obliged if I might reply to the criticisms of my paper on the ancient beaches of Gower (*Proc. Geol. Assoc.*, xliii, 1932, 291) contained in Mr. Baden Powell's letter in the May number of the GEOLOGICAL MAGAZINE (LXX, 1933, 239).

In the first place I would say that none of the beaches, other than the *Patella* Beach, which I described had previously been recorded. Of those which Mr. Baden Powell had reported to occur, I was unable to distinguish his fossiliferous 50 foot beach above his 25 foot beach; and I found it impossible, for reasons given in my paper (p. 296) to separate his 25 foot beach from the equivalent of Mr. Wright's 10 foot pre-Glacial beach. I scarcely provide "confirmation" of Mr. Baden Powell's conclusions, therefore.

The remainder of his criticisms are adequately answered in the paper itself.

I specifically distinguished the *Neritoides* Beach from the *Patella* Beach on stratigraphical grounds: the minor differences between the faunas was a secondary aid in localities where the intervening terrestrial breccia is absent, but they are obviously not an absolute criterion and were not employed as such by me. The reasons for considering the conditions under which the *Patella* Beach was formed to have been cold, and those of the *Neritoides* Beach to have been warm, were not based on the evidence of the marine faunas found in the beaches, which is inadequate and equivocal, but on other grounds (see pp. 294–5, 300, 315, of my paper). Mr. Baden

Powell's remark that the species listed in my paper as occurring in the *Patella* Beach constitute an almost, if not quite, impossible ecological assemblage, would suggest that he is under the impression that they lived where they are now found, which of course they did not: they occur as washed-up debris in a shore shingle, and precisely the same assemblage of dead shells may be found near high-water mark in many of the Gower bays at the present day.

I am in no confusion concerning the " 30 foot " beach of southern England, which was in 1927 and 1928 of Neolithic age, according to Mr. Baden Powell, but which is now probably Mousterian, according to the same authority. I was not concerned with that beach, I did not discuss it in my paper, and I have not attempted to affirm or deny its contemporaneity with any of the Gower beaches. Its correlation with the " 30 foot " beach of Gower (the *Patella* Beach) is Mr. Baden Powell's, not mine. On the other hand, Mr. Baden Powell reached the conclusion in 1927 (GEOL. MAG., LXIV, 436), reiterated in 1928 (ibid., LXV, 48), that the " 30 foot " beach in Gower (correlated with the beach at the same height in Scotland and the south of England) is of post-Glacial age. The remarks in my paper were supplementary to those of Tiddeman, Wright, and Charlesworth in attempting to show that it is nothing of the kind. For the stratigraphical evidence in Gower is abundant and overwhelming that the " 30 foot " beach (the *Patella* Beach) of that district is older than the oldest neighbouring Glacial drift, which is the Older Drift of South Wales; it is therefore pre-Glacial so far as concerns the local application of that term. This was all I wished to assert, and I did not also desire to imply that it is necessarily pre-Pleistocene. It is, however, at least older than the *Neritoides* Beach and the *Rhinoceros hemitoechus* fauna associated therewith, which are of Late Acheulean or Early Mousterian age.

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5th May, 1933.

THE ICE AGE AND EARLY MAN IN YORKSHIRE AND NORTH LINCOLNSHIRE.

SIR,—I have read with the greatest pleasure Professor P. G. H. Boswell's masterly Presidential Address delivered to Section C of the British Association at York this autumn. To the archaeologist it is an epoch-making paper, and perhaps it will not be amiss for me to animadvert upon his references therein to my work conducted in Yorkshire and in north Lincolnshire. Dealing with north Lincolnshire, Professor Boswell states (page 75): " The correlation of the

Kirmington Series with our standard succession will be open to doubt until the laminated silts or associated beds yield implements." In this connection I would remind geologists that I have described and illustrated implements recovered in situ from the upper gravels of the Estuarine Series at Kirmington; and, further, that I have found a few artifacts of Upper Palaeolithic type in the overlying Brown Boulder Clay.[1]

On the same page Professor Boswell says that my "recent discovery of Early Mousterian (Clactonian) implements in the 'Hessle' Boulder Clay (equals ? the Upper Purple Boulder Clay) of Kirmington is of great interest . . ." The implements in question, however, I found in the "Cannon-shot" Gravels at Kirmington,[2] and *not* in the "Hessle" Boulder Clay. Moreover, these "Cannon-shot" Gravels, which I equate with the Upper Purple Boulder Clay, antedate the Estuarine Series, which latter may be observed banked against them.

After proceeding to record my discoveries of stratified Aurignacian implements in a late-glacial deposit near Flamborough [3] and Early Mousterian artifacts in the *Corbicula fluminalis* Gravels of Kelsey Hill and Burstwick,[4] Professor Boswell writes (page 76): "Moreover, recent work by Mr. W. S. Bisat shows that both Upper Purple Boulder Clay and Hessle Clay overlie the Kelsey gravels." In the interest of strict accuracy I have to point out that, in 1930, I published two fully documented and illustrated papers [5] in which I demonstrated this fact both upon archaeological and geological evidences. Mr. Bisat has informed me that at the time he was undertaking his examination of the deposits on Flamborough Head and at Kelsey Hill and Burstwick he was unacquainted with my published results, so that it gives me considerable satisfaction to realize that he has arrived, independently, at similar geological conclusions.[6]

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[1] *Antiq. Journ.*, 1931, July, xi, No. 3, 262–272. *Proc. Prehist. Soc. East Anglia*, 1931, vi, pt. 4, 261–5. *Nature*, 20th August, 1932.
[2] *Antiq. Journ.*, 1931, July, xi, No. 3, 262–272.
[3] Ibid., 1930, Oct., x, No. 4, 371–383.
[4] *Proc. Prehist. Soc. East Anglia*, 1930, vi, pt. 3, 226–233.
[5] See notes 3 and 4.
[6] *Naturalist*, 1932, July, 215–19.

NEW NAMES FOR TWO GENERA OF CARBONIFEROUS CORALS.

SIR,—Dr. H. Dighton Thomas, of the British Museum (Natural History), kindly brought to my attention the fact that the names of two new genera of corals established by me in my paper: "Faune du calcaire carbonifère du bassin houiller de Kousnetzk," [1] have been pre-occupied. These are: *Stylophyllum* gen. n.,[2] a name already used by A. E. Reuss [3] in 1854, and *Craterophyllum* gen. n.,[4] used by Aug. F. Foerste in 1909.[5]

I wish now to replace the first name by the new generic name *Stelechophyllum* (from the Greek word στέλεχος, a trunk or log), and offer the generic name *Cypellophyllum* (from the Greek word κύπελλον, a beaker or cup) for *Craterophyllum mihi*.

In his letter, Dr. H. Dighton Thomas suggested also that it would be desirable if I should designate genolectotypes for the four new genera of corals created by me in the paper under consideration. New genera *Peetzia* [6] and *Cypellophyllum* (= *Craterophyllum* Tolmachoff) are monotypic, with *Peetzia minor* Tolm.[7] and *Cypellophyllum abyssum* (Tolm.) (= *Craterophyllum abyssum* Tolm.)[8] as respective genotypes. Genolectotype of the new genus *Stelechophyllum* (= *Stylophyllum* Tolm.) is *Stelechophyllum venukoffi* (Tolm.) (= *Stylophyllum venukoffi* Tolm.),[9] and that of the genus *Disophyllum* [10] is *Disophyllum symmetricum* (Tolm.).[11]

I. P. TOLMACHOFF.

[1] The paper was published by the Russian Geological Committee in two parts: Part i, in 1924, in *Matériaux pour la Géologie Générale et Appliquée*, livr. 25; part ii, in 1931, as a special publication. As a matter of fact, the first part was printed in 1914, but its continuation was interrupted by the Great War, Russian Revolution, and by the author leaving Russia. The author wishes to use this opportunity for expression of his deep and sincere gratitude to his friends in Russia, A. P. Karpinski, member and President of the Russian Academy of Sciences, and G. N. Fredericks, member of the Russian Geological Committee, who have been chiefly responsible for the appearance of this paper. Without the great authority of the former and the persistent efforts of the second even the first already printed part of the paper would probably never have appeared before the scientific world.

[2] Op. cit., 316 and 606.

[3] A. E. Reuss, "Beiträge zur Charakteristik der Kreideschichten in den Ostalpen, besonders im Gosauthale und am Wolfgangsee": *Denkschr. d. K. Akad. d. Wiss., Math.-Naturw. Cl.*, vii, 132, Wien, 1854.

[4] Op. cit., 344 and 614.

[5] A. F. Foerste, "Fossils from the Silurian Formations of Tennessee, Indiana, and Illinois": *Bull. Sci. Lab. Denison University*, xiv, 101, Granville, Ohio, 1909.

[6] Op. cit., 309 and 603.

[7] Ibid., 312 and 604.

[8] Ibid., 345 and 614.

[9] Ibid., 318 and 607.

[10] Ibid., 341 and 613.

[11] Ibid., 342 and 613.